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ARABIS MOSAIC VIRUS IN STRAWBERRY

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THE diseased strawberry plants studied were collected from various parts of England, and grouped according to their leaf symptoms into two categories described as strawberry mosaic (Posnette, 1956) and yellow crinkle (Harris, 1958). The mosaic syndrome, with clearly defined bright yellow areas on the leaves, occurred only in plants of the Royal Sovereign variety (Fig. 1) and, when these were grafted to Cambridge Favourite plants, the latter developed diffuse mottling and necrotic spots. Huxley's Giant and Cambridge Favourite plants with yellow crinkle (Fig. 2) showed a conspicuous yellow mottle and necrotic spotting, but Royal Sovereign plants grafted to them developed only mild symptoms quite distinct from those of mosaic. It was therefore thought that mosaic and yellow crinkle were distinct virus diseases. To study and identify the viruses responsible, attempts were made to transmit them from strawberry to other hosts.

METHOD OF TRANSMITTING STRAWBERRY VIRUSES TO HERBACEOUS HOSTS.

Sap was extracted by grinding young strawberry leaves with 0·05M phosphate buffer pH 8·9 (1 ml. per gm. of leaf) and squeezing the pulp through muslin. This "standard" extract was rubbed on the leaves of the test plants with Superfloss Celite (Johns-Manville Ltd.) added to facilitate transmission. None of the inoculated seedlings of eight common virus-indicator hosts, including cucumber and tobacco, developed symptoms. Virus transmission occurred readily, however, when the standard inoculum was diluted 1:5, 1:10 or 1:20 with phosphate buffer pH 8·9, presumably because virus inhibitors were less active; systemic symptoms developed on seedlings of *Beta vulgaris* L., *Chenopodium amaranticolor* Coste and Reyn., *Nicotiana tabacum* L., *N. rustica* L., and *Petunia hybrida* Vilm. In this way viruses, later shown to be strains of arabis mosaic virus (Smith and Markham, 1944), were isolated from strawberry plants of several varieties.

No virus could be transmitted from a Huxley strawberry plant (S128) showing yellow crinkle symptoms, however, until young leaves had been infiltrated with phosphate buffer pH 8·9. To increase the absorption of buffer, they were placed in ether for an hour and washed three times in the buffer solution, which was then infiltrated into the leaves by the intermittent application of suction pressure for an hour. After they had been left for a further 5½ hours in phosphate buffer, virus transmission to petunia and *Chenopodium* plants was obtained with sap produced by macerating the treated leaves with Celite.

This S128 isolate was more difficult to transmit from strawberry than a mosaic isolate, S577, which was less sensitive to the inhibitors in the sap of Huxley leaves. This was shown by mixing the sap from petunia plants infected with each

* Holder of a Colombo Plan Fellowship. This paper includes part of a thesis approved for the award of the degree of Ph.D. by London University.

isolate with equal quantities of sap from healthy Huxley plants. The S577 inoculum treated in this way infected *Chenopodium*, whereas the S128 inoculum did not.

Pre-treatment with ether was used without success on other strawberry plants with yellow crinkle symptoms. It is now thought that these plants were infected with viruses that are not sap-transmissible, some containing an undescribed virus transmitted by the strawberry aphid (Anon., 1960).

HOST RANGE OF THE VIRUSES FROM STRAWBERRY.

When the viruses had been transmitted from strawberry to petunia plants, twenty-one species of plants belonging to eight different families were inoculated with extracts of young infected petunia leaves macerated in phosphate buffer pH 8·9.

Seven virus isolates from strawberry plants were transmitted to *Petunia hybrida* Vilm., *Nicotiana tabacum* L. var. White Burley, *N. glutinosa* L., *N. rustica* L., *Lycopersicon esculentum* Mill., *Datura stramonium* L., *Chenopodium amaranticolor* Coste and Reyn., *Beta vulgaris* L., *Phaseolus vulgaris* L. var. Prince, *Cucumis sativus* L. var. Butcher's Disease Resister, *Cucurbita pepo* L. var. Cocozelle, *Vinca rosea* L., *Tithonia speciosa* L., *Callistephus chinensis* Nees. and *Amaranthus retroflexus* L.

Infection was confirmed by inoculating petunia test plants with sap extracts from these host plants, some of which produced distinctive symptoms when infected with different isolates. In cucumber, for example, isolate S439 caused conspicuous chlorotic lesions on the cotyledons and chlorotic mottling on the leaves, whereas isolate S709 caused barely discernible lesions and extreme stunting with necrosis of the growing point. *P. hybrida* seedlings showed the most conspicuous differences in the symptoms caused by different isolates; the S709 isolate produced black etch patterns on leaves and stem quite distinct from the brown or grey etching characteristic of other isolates (Fig. 3).

Attempts were made to isolate viruses from weeds and crop plants collected from strawberry plantations where mosaic and yellow crinkle occurred. Arabis mosaic virus was transmitted only from one plant of *Solanum nigrum* and one of *Carum segetum* to the inoculated petunia and *Chenopodium* test plants. The ornamentals *Daphne mezereum* and *Astilbe* sp. were also found naturally infected with arabis mosaic virus (Posnette and Cropley, personal communication).

IDENTITY OF THE VIRUSES FROM STRAWBERRY.

The symptoms induced in several species of host plants, and the physical properties of the viruses isolated from strawberry, resembled those of raspberry yellow dwarf virus (Harrison, 1958*a*), now known to be a strain of arabis mosaic virus (Cadman, 1960). Plant-protection and serological tests were therefore made with five isolates from strawberry with yellow crinkle or mosaic disease, the raspberry yellow dwarf (RYDV) strain and antiserum, the beet ringspot strain of tomato black ring virus (Harrison, 1958*b*) and raspberry ringspot virus isolated from cherry. The antiserum to RYDV was kindly supplied by Dr. C. H. Cadman.

Plant-protection tests.

The host-range investigation showed petunia to be the most suitable host for plant-protection tests, as it developed systemic symptoms after infection with arabis

PLATE I.

Fig. 1.
Strawberry mosaic disease in Royal Sovereign.

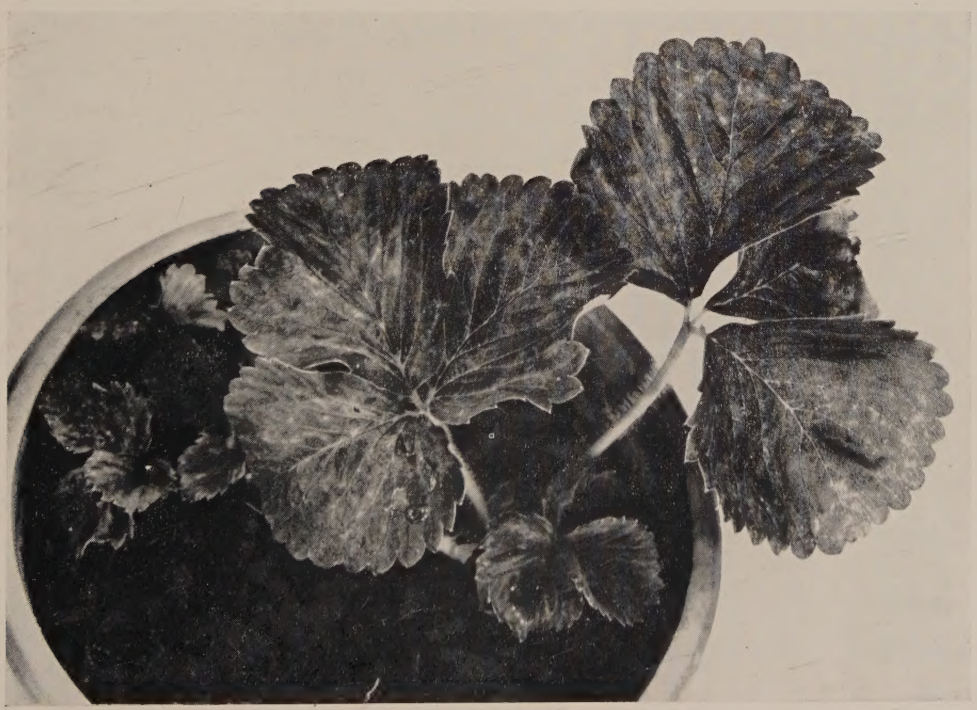

Fig. 2.
Yellow crinkle disease in Cambridge Favourite. Plant infected for two years on left, recently infected plant on right.

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FIG. 3.

Symptoms induced on petunia by isolates of arabis mosaic virus from strawberry. Above: etching characteristic of most isolates. Below: chlorotic rings caused by S128 on left, black etching by S709 on right.

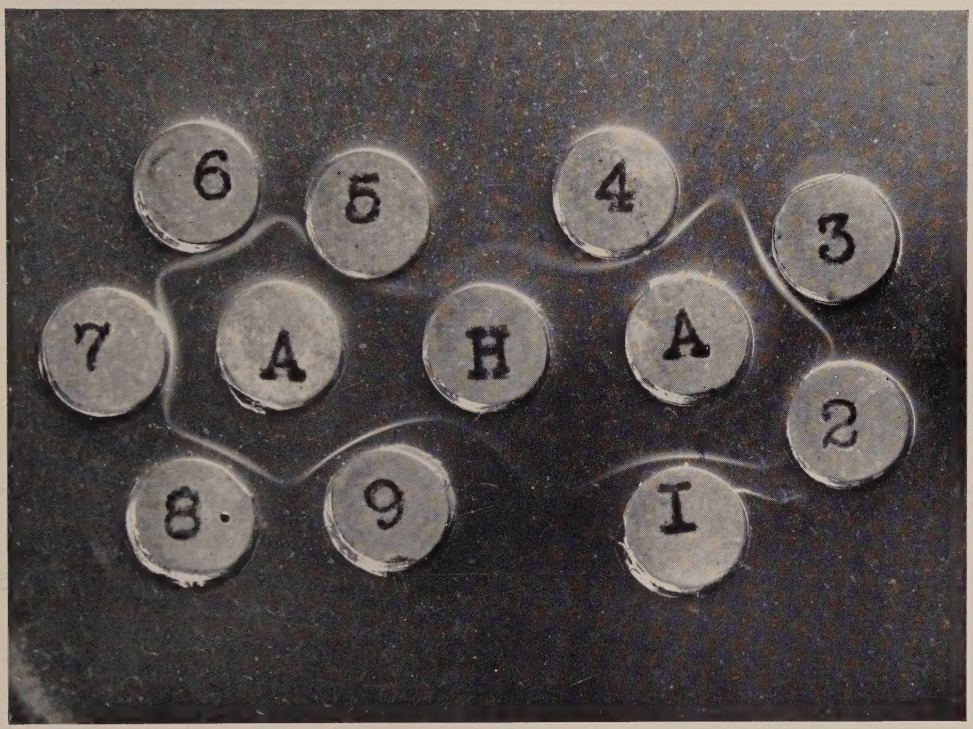

FIG. 4.

Gel-diffusion serological test with arabis mosaic antiserum (A) and infective petunia sap containing: seven isolates from strawberry (1-7), virus obtained from a petunia seedling grown in infective soil (8) and Scottish raspberry yellow dwarf virus (9). Well H contained healthy petunia sap.

mosaic virus, and symptomless leaves were produced later from which the virus could be recovered (Harrison, 1958*a*).

Each isolate was inoculated to the symptomless leaves of a number of petunia plants which had been infected previously with different isolates. Inoculations with the second or challenge isolate were done twice at an interval of 6 days on the same symptomless leaves.

There was no interference between these virus isolates from strawberry and tomato black ring or raspberry ringspot viruses.

Two strawberry mosaic and two yellow crinkle isolates protected against each other completely, but only one of them protected plants against RYDV strain of arabis mosaic virus. When a fifth isolate (S709) was used as the first virus it invariably protected plants against all other isolates from strawberry; when used as the challenge virus, it invaded some of the plants previously infected with each of these isolates, i.e. protection was not reciprocal, and 16 out of 53 plants infected with the four isolates from strawberry became infected when challenged with the S709 isolate.

These results indicated a close relationship between some strawberry isolates and arabis mosaic virus, but not between the latter and the S709 isolate.

Serological tests.

Tube precipitin tests showed that the S709 isolate was serologically related to the raspberry yellow dwarf virus against which the antiserum had been prepared.

Gel-diffusion precipitin tests were made with the RYDV antiserum as shown in Fig. 4. Precipitation lines formed after 4 days' storage at 20° C. showed a relationship between raspberry yellow dwarf virus and the eight isolates from strawberry. When *Chenopodium*, petunia and tobacco plants were infected with arabis mosaic virus derived from the stock culture in *Arabis hirsuta* (kindly supplied by Dr. K. M. Smith, Cambridge) they developed symptoms resembling those caused by the isolates from strawberry. The arabis mosaic virus was tested against the RYDV and the S709 antisera (see below) by the gel-diffusion method, and precipitation lines developed with both antisera, indicating a relationship between this virus and those isolated from strawberry. All the viruses isolated from strawberry are therefore regarded as strains of arabis mosaic virus (Smith and Markham, 1944).

Preparation of an antiserum against S709 virus isolate.

An antiserum prepared against the S709 isolate precipitated at dilutions up to 1/64 with sap from healthy petunia, and to 1/256 with sap from plants infected with each of the isolates from strawberry plants showing mosaic and yellow crinkle.

Effect of temperature on the antigenic properties of the virus.

1 ml. aliquots of centrifuged sap from petunia plants infected with the distinct isolates S128 and S709 were heated for 10 minutes at 45° C., 50° C., 55° C. and 60° C. The antigenic properties of the viruses in gel-diffusion tests with S709 antiserum diluted 1:16 were not affected by temperatures up to 55° C., but were destroyed by 10 minutes at 60° C.

In another experiment with the same isolates, the different temperatures were maintained for 10 minutes, ½ hour, 1 hour, 1½ hours and 2 hours. Antigenicity was lost at 50° C., 55° C. and 60° C. on heating for 2 hours, 1 hour and 10 minutes re-

spectively. The antigenic property of the virus was not affected at 45° C. for 2 hours. Both isolates behaved alike, although the thermal inactivation point of infectivity of the S128 isolate was apparently higher than that of the S709 isolate.

TRANSMISSION OF ARABIS MOSAIC VIRUS TO STRAWBERRY.

Standard extracts from petunia plants systemically infected with strawberry virus isolates S439, S709 and S710 were prepared separately, and then further diluted 1:20 with phosphate buffer pH 8·9. One strawberry plant of each of the varieties Cambridge Favourite and Cambridge Vigour was inoculated with each isolate by (*a*) rubbing the leaves with inoculum mixed with Celite, and (*b*) pricking the leaves, roots and crown with a needle previously dipped into infective sap.

The S709 isolate infected the Cambridge Favourite strawberry plants inoculated by both methods, and was readily transmitted from them to petunia plants. No infection with the S439 and S710 isolates occurred.

In an attempt to find the most effective method of inoculating strawberries, plants of the varieties Cambridge Favourite and Royal Sovereign were used and, as inocula, standard extracts of the raspberry yellow dwarf, S709 and cherry isolates of arabis mosaic virus diluted 1:10 with phosphate buffer. Five plants of each variety were inoculated with each isolate, using four different techniques. One Cambridge Favourite plant was infected with the S709 isolate by inoculating the upper surfaces of the leaves, using a glass pestle and Celite. Two Royal Sovereign plants were infected in the same way, using 500 mesh carborundum. Similar inoculations with the other isolates were unsuccessful, as were attempts to introduce them by needle inoculations to the leaves, roots and crown. Only the S709 isolate, therefore, yielded inoculum capable of overcoming the resistance of strawberry plants to manual inoculation.

Influence of temperature and shade on the susceptibility of the strawberry plant to virus infection.

An attempt was made to increase the susceptibility of strawberry plants to virus infection by subjecting them to heat and excluding light for 24 hours prior to inoculation with the S709 isolate. Celite was added to the inoculum prepared from infected petunia plants, and carborundum powder (500 mesh) dusted on the strawberry leaves before inoculation. Six Cambridge Favourite plants were subjected to each of four treatments. One of the plants kept in the dark at normal glasshouse temperatures and one of the group kept in the darkened incubator at 37° ± 2° C. became infected. Apparently shading increased the susceptibility of the plants, as all the unshaded plants remained healthy whether they were in the incubator or outside.

ATTEMPTS AT THERMAL INACTIVATION *IN VIVO*.

An attempt was made to inactivate arabis mosaic virus in strawberry and *Vinca rosea* plants by heat-treatment. *Vinca rosea* was chosen because it was found to tolerate heat for long periods (Kunkel, 1941).

In the first experiment, five Cambridge Favourite strawberry plants, naturally infected with arabis mosaic virus, were maintained at 37° ± 2° C. They were removed from the heat chamber after 2 weeks, when no virus could be detected by

inoculating petunia seedlings. The treated plants were then propagated by the crown-cutting method (Posnette and Jha, 1960); 5 out of 52 cuttings survived but all subsequently developed symptoms and arabis mosaic virus was transmitted from them to petunia and *Chenopodium* test seedlings.

In similar experiments virus was recovered from the roots of *Vinca* plants immediately these were removed from the incubator, whether they had been kept for 1, 2, 3, or 4 weeks at 37° C. or at 40° C.

These results suggest that arabis mosaic virus cannot be completely inactivated *in vivo*. It seems improbable that this failure is due to the temperature of the roots being lower than that of the leaves, as the virus was inactivated in leaves after 3 weeks at 37° C. but not in roots after 4 weeks at 40° C. Moreover, the temperature of the soil was only 2° C. lower than that of the air.

SOIL TRANSMISSION OF YELLOW CRINKLE DISEASE.

In October 1957, Posnette and Cropley (unpublished) collected soil from the site of an outbreak of yellow crinkle disease at Sutton Valence, Kent, and tested its infectivity by growing strawberry plants in it. In September 1958, soil from four pots in which strawberry plants had become infected with yellow crinkle was used for potting four healthy Cambridge Favourite plants and eight cucumbers. The cucumbers showed no symptoms after 6 weeks and no virus was recovered from their roots. However, 3 of the strawberry plants showed yellow crinkle after 6 months and virus was also recovered from the roots of petunia seedlings planted to replace the cucumbers.

Healthy strawberry and petunia plants also became infected when grown in 4 in. pots of soil collected from two levels (0-9 in. and 9-18 in.) in four different regions of the Sutton Valence site. Controls in sterilized soil or in soil from a healthy part of the plantation remained healthy and virus was not recovered from their roots after 6 months.

Dilution end-point of virus infectivity of soil.

Soil was collected from the same site at Sutton Valence and large aggregates were broken down to bring it to a fine crumb. The soil was then mixed with different quantities of steam-sterilized soil in the proportions 1:1, 1:10, 1:100, 1:1,000. Approximately 800 gm. of each mixture were placed in each of five 4 in. clay pots. Bait seedlings of petunia and turnip were grown for 3 months in these pots, after which sap from the roots of all seedlings in each pot was used to inoculate petunia and *Chenopodium* test seedlings.

This experiment showed that the dilution end-point of the infectivity of this soil was between 1:100 and 1:1,000. As each pot contained about 800 gm. of mixed soil this suggested that one infective unit was present in approximately 8 gm. of soil from the field site. This density is similar to the estimated population density of dagger nematodes later found in the soil from the same site, viz. one nematode per 12 gm. of soil.

Attempts to detect the presence of "free" virus in the soil by mechanical transmission.

The first reported outbreaks of arabis mosaic virus in strawberry and raspberry occurred on heavy soils (Lister, 1958) and, as it seemed possible that the virus might

be adsorbed on clay particles, the following investigation was made to ascertain whether arabis mosaic virus could be recovered directly from soil constituents.

From silt and clay fraction. The silt and clay fraction was obtained by repeatedly shaking infective soil with equal volumes of water and decanting the fractions which failed to settle after standing for 5 minutes. These suspensions were filtered through 300-mesh sieves and then through filter paper to obtain the silt and clay. This was mixed with two volumes of autoclaved sand and two of vermiculite. Petunia seedlings grown in this mixture for 6 months did not show symptoms of arabis mosaic, and tobacco necrosis was the only virus obtained from the roots by sap inoculation to *Chenopodium*.

From supernatant liquid. The filtrate obtained after removing the clay particles was used for watering 10 petunia test plants growing in steam-sterilized soil, 40 ml. being used daily for each pot for 5 days. These test plants were kept under observation for 3 months; no symptoms were observed and tobacco necrosis was the only virus transmitted from their roots.

500 ml. of the filtrate was allowed to stand in a 1-litre measuring cylinder for 24 hours at room temperature. The top 10 cm. was drawn off and the suspended particles were concentrated by centrifugation at 10,000 r.p.m. for 15 minutes. The pellet of soil particles was mixed with 1 ml. of phosphate buffer pH 8·9, and rubbed on the leaves of petunia and *Chenopodium* test seedlings. Tobacco necrosis virus was obtained in this way but not arabis mosaic.

Any virus remaining in the supernatant after centrifugation was precipitated by adding an equal volume of acetone. The mixture was shaken vigorously and then centrifuged at 10,000 r.p.m. for 15 minutes. The pellet was mixed with 0·5 ml. of phosphate buffer pH 8·9, and rubbed on *Chenopodium* leaves. This test also revealed the presence of tobacco necrosis virus, but not of arabis mosaic virus.

Attempted transmission through soil by sap extracts.

Standard extract of sap from petunia plants systemically infected with the S709 virus was diluted 1:50 with phosphate buffer pH 8·9. This suspension, shown to be infective by inoculation, was added (at the rate of 20 ml. per pot) to 5 pots each containing 2 healthy petunia plants growing in sterilized potting compost. This procedure was repeated for 5 days and afterwards tap water was used for watering. No symptoms developed on the plants during a period of 4 months and no virus was transmitted from their roots to petunia or to *Chenopodium* seedlings. This experiment was repeated with single petunia plants in 10 pots and no virus infection was detected.

Attempt to recover arabis mosaic virus from soil containing decomposed infected plant material.

Twenty young petunia seedlings with severe symptoms of the S709 isolate were macerated and covered with layers of steam-sterilized soil (5,000 gm.) in a clay pot. This material was kept moist for 3 months after which the soil was mixed with the thoroughly rotted plant debris. None of the petunia and turnip seedlings grown in this soil for 2 months became infected. This suggests that the perpetuation of this virus under field conditions is not due to the presence of the debris of the infected plants and that the agency of transmission through soil differs from that of tobacco necrosis virus (Smith, 1937) and the Japanese cereal mosaic virus (Miyamoto, 1959).

DETERMINATION OF THE VECTOR IN INFECTIVE SOIL.

Attempts to transmit arabis mosaic virus by an endotrophic mycorrhizal fungus.

Microscopical examination of the roots of naturally infected strawberry plants revealed the presence of *Pratylenchus* nematodes inside the root tissues, and also of mycorrhizal mycelium of *Endogone* sp. (Mosse, 1956). Since previous attempts to transmit arabis mosaic virus with *Pratylenchus* had failed (Posnette and Pitcher, unpublished), the mycorrhizal fungus was tested as a vector.

Eight petunia plants growing singly in pots containing autoclaved sand and loam were inoculated with arabis mosaic virus (S709 isolate) which was recovered from their root systems 2 weeks later. Fifty sporocarps of an *Endogone* sp. (kindly supplied by Dr. Barbara Mosse) were placed near the roots of 5 of these petunia plants (infectors), leaving 2 plants without sporocarps as controls. After 3 months, petunia seeds were sown in the same pots, and the aerial parts of the infectors were removed to avoid contact with the leaves of the test seedlings. After 3 months, roots of infector plants and test seedlings were examined for mycorrhiza, and the fungus was present in all plants except the controls. None of the test seedlings was found to be infected with virus, however, when their roots were tested by inoculation.

Failure to demonstrate virus transmission by the *Endogone* mycelium occurred again with strawberry plants in an experiment with *Xiphinema* nematodes. The control series of pots each contained a healthy and a virus-infected strawberry plant, each with mycorrhiza but without nematodes, and no virus transmission was subsequently recorded (Jha and Posnette, 1959).

Examination of the nematode content of "healthy" and infective soil.

Soil that had been collected in 1957 from three field outbreaks of yellow crinkle, and had proved infective in glasshouse tests, was examined for nematodes in October 1958. Dagger nematodes, later identified as *Xiphinema diversicaudatum* (Micol.), were present in some pots of soil from each outbreak and, as a related species had been reported as a vector of fanleaf virus of grape vines in California (Hewitt *et al.* 1958), they were tested as vectors of arabis mosaic virus. The results already published (Jha and Posnette, 1959, 1961), showed that the dagger nematodes transmit arabis mosaic virus in a manner similar to the insect-transmission of a persistent virus, i.e. the vector remains infective for long periods.

DISCUSSION.

The viruses transmitted by sap inoculation from strawberry plants with mosaic and yellow crinkle diseases all proved to be serologically related to arabis mosaic virus. The difference between mosaic and yellow crinkle symptoms on those plants was presumably related to difference between the causal virus strains, as these induced distinct symptoms in some alternative hosts. The isolates also differed in their reaction to inhibitors in strawberry sap and only one (S709 from a Cambridge Favourite plant with yellow crinkle) was transmitted to strawberry plants inoculated with sap from herbaceous hosts infected with it. This isolate produced symptoms on petunia so different from those caused by other isolates that it was at first thought to be a distinct virus; but although plant-protection tests gave equivocal results, serological tests proved it to be related to arabis mosaic virus.

The plant-protection results indicate a degree of strain differentiation not detected by serological methods, as reported by Harrison (1958*b*) for tomato black ring virus. Both the S709 isolate and the raspberry yellow dwarf strain were able to invade and induce symptoms on plants infected with each of the other isolates; the latter were, however, unable to affect plants infected with either the raspberry yellow dwarf or the S709 strain. Cadman (1960) found little variation in antigenicity among arabis mosaic isolates from different countries, but the isolates obtained in this work from strawberry differed considerably in virulence and the symptoms induced on several host species.

About half the plants with yellow crinkle symptoms failed to yield a sap-transmissible virus but some of these proved to be infected with a complex of viruses transmissible by the strawberry aphid *Pentatrichopus fragaefolii* (Cock.) (Ellenberger, unpublished). Lister (1958) has shown that a similar disease of strawberry may also be caused by infection with raspberry ringspot and tomato black ring viruses. Clearly, therefore, symptoms of the yellow crinkle type on strawberry plants are not indicative of infection by one particular virus, and the causal virus must be isolated before it can be identified.

Strawberry mosaic disease, as originally described on the Royal Sovereign variety, is characterized by discrete yellow blotches. It is known that several strains of the causal virus (arabis mosaic) occur, some of which produce only a slight mottle on Royal Sovereign plants and more conspicuous symptoms on Cambridge Favourite, Cambridge Prizewinner and Huxley's Giant. Because of the previous association of the term "crinkle" with diseases caused by aphid-transmitted viruses, it seems logical to use in future the name "strawberry mosaic" for both mild and severe forms of the disease caused by strains of arabis mosaic virus.

SUMMARY.

Viruses transmitted by sap inoculation from strawberry plants with mosaic and yellow crinkle diseases to herbaceous hosts were all identified as strains of arabis mosaic virus. One isolate was transmitted from petunia back to strawberry plants.

Serological and plant-protection tests showed that all isolates from strawberry were related to arabis mosaic virus and not to raspberry ringspot and tomato black ring viruses.

Infected strawberry and *Vinca rosea* plants were not cured by heat treatment for periods up to 4 weeks at 40° C.

Unlike tobacco necrosis virus, arabis mosaic virus was not isolated from infective soil. It was not transferred from infected to healthy plants by mycorrhizal mycelium of *Endogone* sp., and transmission was obtained only by means of dagger nematodes (*Xiphinema diversicaudatum*).

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SOIL FOR JOHN INNES COMPOSTS

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Soil from under grass is considered a desirable constituent of John Innes composts (Lawrence and Newell, 1952) and some growers sow leys to produce it on their own nurseries. The sowing rate may be as high as 6 oz./sq. yd. (Chaplin, 1953). Such soil is likely to have a stable crumb structure and a high content of actively decomposing organic matter supplying nitrogen.

Several workers in Great Britain have studied the increase in aggregate stability under leys (Clement and Williams, 1958; Emerson, 1954; Low, 1955; Pringle and Coutts, 1956). Clement (1956) found that the yield of wheat on plots which had been under different leys was highly correlated with the amount of mineral nitrogen released on incubation.

To assess the relative merits of soils from different leys for use in John Innes composts three soils of different mechanical analyses were sown with four grasses. Other areas of each soil were kept under bare fallow for purposes of comparison. It was decided to compare the nitrogen content and aggregate stability of soil samples from the various leys and to see whether either of these soil characteristics could be correlated with the germination or growth of seedlings in seed and potting mixtures containing the soils. After the leys had been sown for two years, seedlings were grown in potting mixtures containing soil from the various leys. No significant differences in seedling fresh weight were detected.

Methods.

The mechanical analyses were carried out by the revised official method as drafted by the Agricultural Education Association (1928). After soils had been incubated for 20 days at 30° C. Bremner and Shaw's (1955) method was used to determine the ammonia plus nitrate contents. These will be referred to as "nitrogen" contents.

Soil is vigorously disturbed when being shredded, sterilized and mixed for use in John Innes composts. Therefore, the resistance of soil aggregates to wet-sieving was estimated by Low's (1954) method, which was the most drastic treatment tested by Williamson *et al.* (1956). Such resistance will be referred to as "aggregate stability" in this paper. The value for aggregate stability was calculated as the ratio:

$$\frac{\text{Wt. of aggregates remaining on 2 mm. sieve}}{\text{Original wt. of aggregates of 3–5 mm. diam.}} \times 100$$

John Innes composts undergo many wetting and drying cycles when in pots and seed pans, and resistance of aggregates to breakdown by wetting was estimated by the method of Flunt and Zeller (1951). In this method the soil is wetted, air-dried,

and then sieved. The value for resistance to wetting was calculated as the ratio:

$$\frac{\text{Wt. of aggregates remaining on } \frac{1}{2} \text{ mm. sieve}}{\text{Original wt. of aggregates of } \frac{1}{2}\text{–}2 \text{ mm. diam.}} \times 100$$

In this paper " seed and potting mixtures " will refer to mixtures of soil, peat, sand and fertilizers, and " seed and potting soils " to mixtures of soil and fertilizers. The term " compost " will be reserved for mixtures adhering strictly to the formulae for the John Innes composts.

Growth of seedlings was judged by their fresh weight, which is highly correlated with dry weight when the standard techniques developed at Bayfordbury are used (Lawrence, 1955). For tomato, $r = 0{\cdot}970$ with 30 d/f; for antirrhinum, $r = 0{\cdot}931$ with 48 d/f.

Preparation of leys; chemical and physical comparisons.

Sowing and management of leys.

Leys were sown on three areas of the Bayfordbury estate where the previous cultivations were likely to have reduced aggregate stability. The soils in these areas were of different textures and their clay content ranged about that considered ideal for the making of John Innes composts, i.e. about 25%. Except that two of the soils contained carbonates, their mechanical analyses were such that they could be considered as possible substitutes for the loam recommended by Lawrence and Newell (1952), if that were unavailable. Four grasses and one mixture were used. They were sown at the following rates per acre: ryegrass (S.23) 20 lb., cocksfoot (S.143) 15 lb., fescue (S.59) 12 lb., timothy (S.50) 7 lb., mixture of 50% cocksfoot and 50% fescue 12 lb. They were also sown at ten times these rates, which are approximately the rates used by some nurserymen.

Some plots were mown regularly so that the grass was never more than about 3 in. high. The other plots were mown only twice a year, once to prevent flowering and once at the end of the growing season. All mowings were removed. The fallow plots were kept free of all plant growth by regular hoeing.

As it is desirable that soil for use in potting mixtures should have a pH less than 6·3, the plots were not dressed with lime or with fertilizers that might raise the pH. Clover was not sown as it is not likely to thrive under such treatment, especially on those plots mown only twice a year. Before sowing and at the beginning of each season, fertilizers were applied at the following rates per acre: sulphate of ammonia 1 cwt., superphosphate 2 cwt., sulphate of potash 1 cwt. A further 1 cwt./acre of sulphate of ammonia was applied to all ley plots after the mowing to prevent flowering. At the same two times the same quantities of fertilizers were also applied to the fallow plots.

Soil samples, 4 in. deep, were taken in May when turves for use in John Innes composts are normally cut. Nitrogen determinations were made in the fourth year after sowing. Aggregate stabilities were tested each year. In the fourth year the aggregate stabilities of soils of similar mechanical analyses on which grass had been growing for over ten years were also tested. Such tests would indicate the potential aggregate stability of each soil. Also the aggregate stability of samples from the ryegrass, fescue and bare fallow plots on all three soils were measured after sterilization. The samples were then wetted to field capacity and left for 48 hours to become air-dry. Then their aggregate stabilities were measured again.

Comparison with standard seed and potting mixtures and soils.

Seed and potting mixtures and soils were prepared containing soil with the following mechanical analysis: coarse sand 8%, fine sand 47%, silt 17%, clay 23%. This soil had been down to grass for over ten years in 1958 and will be referred to as "old grassland" in this paper. The pH of fresh potting mixtures made with this soil was $6{\cdot}2 \pm 0{\cdot}03$ and that of fresh potting soils was $6{\cdot}4 \pm 0{\cdot}05$. The pH may vary considerably during the course of an experiment (Bunt, 1956).

The nitrogen contents (mg./kg.) during different stages of the preparation of this soil for use in seed and potting mixtures were: before stacking 77, after stacking 122, after stacking and sterilizing 214. The nitrogen content after sterilizing only was 133 mg./kg. This last value would compare with the values given for sterilized soil in Table I.

The nitrogen contents (in mg./litre) of these mixtures and of their constituents were: seed mixture 100, potting mixture 203, soil 199, peat 25, sand 0. The figures are expressed on a volume basis as the constituents were mixed on this basis. The rise in nitrogen content of JIP1 caused by the addition of hoof and horn is partly counteracted by the addition of about 42% by volume of peat and sand which has a low nitrogen content compared with the stacked and sterilized soil.

The aggregate stability was $66 \pm 2{\cdot}5$. This soil would be considered fairly suitable for use in John Innes composts. When studying germination and growth in mixtures containing the ley soils, mixtures containing this old grassland soil were used as bases of comparison.

Seed and potting mixtures and soils.

Seed and potting mixtures and "soils" were also made with soils from under the various leys after they had been down for four years. Seeds of the quick-germinating *Antirrhinum majus* and the slow-germinating *Primula sinensis* were sown in mixtures and soils containing the fertilizers used in JIS. Seedlings of the quick-growing tomato Potentate and the slow-growing *Antirrhinum majus* were grown in mixtures and soils containing JIP1 fertilizers. These species were considered representative of those likely to be grown on a nursery.

Soils from the four-year leys were treated in the following ways:

(*a*) Allowed to dry out, partially sterilized with steam, and mixed with peat, sand and fertilizers in the proportions used in J.I. composts.

(*b*) Stacked as recommended by Lawrence and Newell (1952) and then partially sterilized. Some of this soil was then mixed as in (*a*), whilst some of it had only the J.I. base fertilizers added.

Properties of the three soils used.

Details for each soil under ley are given below. The figures given for leys in the Tables are averages for plots sown at different rates and subjected to different mowing systems.

Soil A.

Mechanical analysis: coarse sand 32%, fine sand 27%, silt 10%, clay 18%, carbonates 6%.

Cropping history: 1943 wheat, 1944 roots, 1945 spring oats, 1946 ley, 1947–52 raspberries, 1953 bare fallow.

The grass was sown on 21st April 1954.

As this soil contained carbonates, chalk was not added to the seed and potting mixtures and soils. The average pH of potting mixtures containing soils from the various leys was $6{\cdot}7 \pm 0{\cdot}14$, and of potting soils $7{\cdot}0 \pm 0{\cdot}18$.

The aggregate stability in 1958 of samples taken from adjacent grass verges which had carried grass for over ten years was $10{\cdot}7 \pm 1{\cdot}29$. In 1958 the aggregate stabilities of samples from ryegrass, fescue and bare fallow plots were measured (*a*) before sterilizing, (*b*) after sterilizing, and (*c*) after sterilizing and one subsequent wetting and drying cycle. The values were:

	(*a*)	(*b*)	(*c*)	
Ryegrass and fescues (average)	7·6	9·8	7·7	±0·92
Bare fallow	0·8	2·4	1·7	

The results of the chemical and physical analyses are set out in Tables I and II and of the germination and growth experiments in Tables V and VIII.

Soil B.

Mechanical analysis: coarse sand 12%, fine sand 43%, silt 18%, clay 21%.

Cropping history: 1942 oats, 1943 wheat, 1944 sugar beet, 1945 barley, 1946–52 wheat, 1953 bare fallow.

The grasses were sown on 22nd April 1954.

The potting mixtures containing soil from the various leys had average pH $5{\cdot}7 \pm 0{\cdot}23$, and the potting soils pH $6{\cdot}0 \pm 0{\cdot}26$.

The aggregate stability of soil of a similar mechanical analysis on which grass had grown for over ten years was $66 \pm 2{\cdot}5$ in 1958. The aggregate stabilities of samples taken from the ryegrass, fescue and bare fallow plots in 1958 were measured (*a*) before sterilizing, (*b*) after sterilizing, and (*c*) after sterilizing and one subsequent wetting and drying cycle. The values were:

	(*a*)	(*b*)	(*c*)	
Ryegrass and fescue (average)	32·6	65·5	39·9	±2·04
Bare fallow	2·6	19·5	1·3	

The results of the chemical and physical analyses are shown in Tables I and III, and of the germination and growth experiments in Tables VI and IX.

Soil C.

Mechanical analysis: coarse sand 14%, fine sand 27%, silt 18%, clay 29%, carbonates 1%.

Cropping history: 1941 oats, 1942 beans, 1943 and 1944 wheat, 1945 beans, 1946–53 wheat (occasionally undersown), 1954 bare fallow.

The grasses were sown on 4th April 1955.

As this soil contained carbonates, chalk was not added to the seed and potting mixtures and soils. Potting mixtures containing soil from the various leys had average pH $6{\cdot}3 \pm 0{\cdot}25$, and potting soils pH $6{\cdot}6 \pm 0{\cdot}19$.

The aggregate stability of soil of a similar mechanical analysis taken from verges on which grass had grown for over ten years was $56{\cdot}0 \pm 1{\cdot}64$ in 1959. The aggregate stabilities of samples taken from the ryegrass, fescue and bare fallow plots in 1959

were measured (*a*) before sterilizing, (*b*) after sterilizing, and (*c*) after sterilizing and one subsequent wetting and drying cycle. The values were:

	(*a*)	(*b*)	(*c*)	
Ryegrass and fescue (average)	36·4	48·5	36·5	±3·00
Bare fallow	17·5	29·4	21·6	

The results of the chemical and physical analyses are shown in Tables I and IV and of the germination and growth experiments in Tables VII and X.

EXPERIMENTAL RESULTS AND DISCUSSION.

Nitrogen (table i).

Unsterilized soil from the plots sown with fescue, either alone or with cocksfoot, tended to contain less nitrogen than soil from the other ley plots. Steam sterilization caused a larger increase in the nitrogen content of soils from the leys than from the corresponding bare fallows.

Table I.

Effects of different leys on the nitrogen content (p.p.m.) of the three soils (A, B, C).

	Unsterilized			Sterilized		
	A	B	C	A	B	C
Ryegrass	64	108	99	124	157	157
Cocksfoot	74	103	106	143	176	163
Timothy	57	100	99	129	170	161
Fescue	53	94	87	131	165	147
Cocksfoot plus fescue..	54	98	91	126	160	155
Bare fallow	61	88	111	83	120	129
S.e. of mean	6·0	5·8	4·8	6·9	7·3	6·6
High sowing rate ..	64	103	97	127	165	159
Low sowing rate ..	58	90	95	132	162	166
Mown regularly ..	65	95	93	133	159	167
Mown twice a year ..	57	98	99	126	168	158
S.e. of mean	3·4	3·3	2·8	3·9	4·1	3·8

The effects of different sowing rates and mowing procedures on nitrogen content of the soils were negligible, except for the effect of the sowing rates for the leys on soil B (21% clay).

Aggregate stability (tables ii, iii and iv).

Samples of all three soils taken from all the leys contained a significantly higher percentage of stable aggregates than samples taken from the bare fallow plots. After four years it was not possible to distinguish between the effects of the leys, but ryegrass may have produced the most rapid improvement of aggregate stability on

Table II.

Effects of different leys on aggregate stability and resistance to wetting of soil A.

	Aggregate stability				Resistance to wetting			
	Year of sampling				Year of sampling			
	1955	1956	1957	1958	1955	1956	1957	1958
Ryegrass	0·20	5·4	12·2	8·9	74	77	84	77
Cocksfoot	0·39	3·8	6·4	8·2	75	74	79	74
Timothy	0·36	3·2	8·9	8·2	72	71	79	74
Fescue	0·31	3·3	3·7	6·6	74	76	77	76
Cocksfoot plus fescue	0·30	7·5	6·5	7·1	76	77	82	79
Bare fallow ..	0·32	0·3	0·1	0·8	75	58	62	66
S.e. of mean ..	0·34	1·21	0·96	1·31	2·0	2·7	3·8	2·1
High sowing rate..	0·37	4·3	7·3	8·3	76	72	80	76
Low sowing rate ..	0·24	3·3	6·9	6·9	73	71	79	75
Mown regularly ..		3·6	7·1	7·5		73	81	76
Mown twice a year		4·1	7·1	7·9		70	78	75
S.e. of mean ..	0·18	0·79	0·54	0·76	1·0	1·4	2·3	1·2

Table III.

Effects of different leys on aggregate stability and resistance to wetting of soil B.

	Aggregate stability				Resistance to wetting			
	Year of sampling				Year of sampling			
	1955	1956	1957	1958	1955	1956	1957	1958
Ryegrass	5·0	19·9	26·3	38·6	80	80	81	84
Cocksfoot	7·0	20·3	25·8	33·2	81	83	80	84
Timothy	5·7	22·5	21·3	34·3	84	80	79	81
Fescue	2·1	17·9	12·3	34·4	83	80	78	84
Cocksfoot plus fescue	5·9	17·7	19·3	35·8	84	81	82	82
Bare fallow ..	1·6	5·1	1·4	2·6	73	57	63	55
S.e. of mean ..	1·70	1·96	1·50	2·38	1·8	1·4	1·4	1·3
High sowing rate ..	5·2	18·5	20·7	32·4	83	80	81	82
Low sowing rate ..	4·5	16·5	17·7	33·0	81	78	79	82
Mown regularly ..		18·9	19·2	34·1		79	80	84
Mown twice a year		16·1	19·2	31·2		79	80	80
S.e. of mean ..	0·98	1·12	0·86	1·37	1·0	0·8	0·8	0·7

TABLE IV.

Effects of different leys on aggregate stability and resistance to wetting of soil C.

	Aggregate stability				Resistance to wetting			
	Year of sampling				Year of sampling			
	1956	1957	1958	1959	1956	1957	1958	1959
Ryegrass	37·5	28·3	43·6	37·4	84	83	90	88
Cocksfoot	28·0	28·5	44·5	37·8	81	83	90	89
Timothy	33·6	31·0	45·5	39·3	85	83	91	89
Fescue	32·3	19·0	42·6	35·9	85	82	90	88
Cocksfoot plus fescue	30·3	27·7	43·6	36·9	84	86	90	88
Bare fallow ..	14·9	9·1	21·6	17·5	75	70	80	85
S.e. of mean ..	1·65	1·61	1·21	1·72	0·9	0·9	1·0	1·6
High sowing rate ..	33·5	26·5	43·6	36·0	85	83	90	88
Low sowing rate ..	32·3	26·1	42·0	36·8	83	82	90	88
Mown regularly ..		26·3	42·6	37·1	85	83	88	88
Mown twice a year		26·3	43·0	35·7	83	82	92	88
S.e. of mean ..	0·94	0·93	0·70	0·99	0·5	0·5	0·6	0·9

soil A (18% clay). The difference in aggregate stability between soils from the ley and from the bare fallow plots was particularly marked in soil B (21% clay). The aggregate stability of soil C (29% clay) from the bare fallow plots was high enough to suggest that there was some residual effect from those previous wheat crops that had been undersown.

The effects of sowing rate and of mowing on aggregate stability were negligible.

The figure of 10·7% (p. 231) for the aggregate stability of samples taken from soil A, which had been down to grass for over ten years, is probably the maximum attainable and the figures in Table II illustrate that this maximum was almost attained in 1958. The relevant figures for soils B and C suggest that their potential aggregate stability is much higher than that of soil A and that the maximum aggregate stability has not been approached after four years under ley.

Van Bavel (1950) reported that heat sterilization increased the aggregate stability of soils, but that a single subsequent wetting and drying cycle reduced the aggregate stability to approximately its original level. This was confirmed by the results for the three soils studied in this paper. This process approaches that undergone by soil used in John Innes composts which is dried, sterilized and then watered after seedlings have been planted in it. Thus, the values for aggregate stability of soil taken from the field, which are shown in Tables II–IV, should provide a fair guide to the structural state of the soil when seedlings are first planted in it.

RESISTANCE TO WETTING (TABLES II, III AND IV).

All the grass leys on all soils except C (29% clay) produced a greater resistance to wetting than the bare fallows.

The effects of different sowing rates and mowing procedures were negligible except for the effect of the mowing systems on the leys on soil B (21% clay).

Germination (tables v, vi and vii).

There were no significant differences in germination of seed sown in seed mixtures or soils containing soil from the different leys. The germination of primula in seed soils containing soil C (29% clay) from the bare fallow plots was significantly lower than that in seed soil containing soil from old grassland. Apart from this, germination in mixtures or soils containing soil from the bare fallow plots was as high as, or higher than, that in mixtures containing soil from the leys or the old grassland.

The differences in germination caused by using soil from leys sown at different rates were negligible. This also applied to soil from leys mown regularly or twice a year except for the germination of antirrhinum in mixtures containing unstacked soil B (21% clay).

There were no significant differences in germination of seed sown in mixtures containing stacked soil.

Growth (tables viii, ix and x).

In soil from the leys.

When used for potting, soil C (29% clay) from the ryegrass ley produced heavier antirrhinum seedlings than soil C from the timothy ley. For use in potting mixtures,

Table V.

Germination in seed soils and mixtures containing soil A from different leys (angular transformations of germination percentages).

	Antirrhinum			Primula		
	Not stacked	Stacked		Not stacked	Stacked	
	Mixed with peat and sand		Soil only	Mixed with peat and sand		Soil only
Ryegrass	51·5	48·9	54·1	33·7	38·1	36·8
Cocksfoot	51·5	54·4	50·1	38·1	40·2	37·4
Timothy	51·1	52·8	53·2	36·2	41·5	34·7
Fescue	53·3	50·3	60·8	30·5	42·4	50·2
Cocksfoot plus fescue ..	51·9	48·7		31·7	37·4	
Bare fallow	50·6	58·8	50·9	34·6	49·2	42·1
Old grass	43·3	60·1	55·0	36·8	40·9	40·8
S.e. of mean	2·95	5·03	5·03	3·78	5·48	5·48
High sowing rate ..	50·5	50·7		37·7	39·0	
Low sowing rate ..	52·2	53·3		34·3	40·8	
Mown regularly ..	51·7	48·9		36·5	40·2	
Mown twice a year ..	51·0	55·1		35·5	39·6	
S.e. of mean	1·20	2·05		1·54	2·24	

TABLE VI.

Germination in seed soils and mixtures containing soil B from different leys (angular transformations of germination percentages).

	Antirrhinum			Primula		
	Not stacked	Stacked		Not stacked	Stacked	
	Mixed with peat and sand		Soil only	Mixed with peat and sand		Soil only
Ryegrass	52·9	50·2	50·8	37·9	47·1	43·5
Cocksfoot	54·0	47·2	46·3	34·8	44·7	56·8
Timothy	49·8	49·1	45·6	40·1	43·7	50·5
Fescue	53·4	48·1	45·6	39·4	48·0	49·1
Cocksfoot plus fescue ..	53·2	50·2		26·6	46·2	
Bare fallow	55·8	48·5	46·3	59·1	58·8	54·8
Old grass	47·8	45·0	46·9	48·0	49·8	44·6
S.e. of mean	3·05	3·12	3·12	5·44	5·85	5·85
High sowing rate ..	51·9	48·1		36·3	40·9	
Low sowing rate ..	52·6	49·6		38·9	49·4	
Mown regularly ..	54·9	50·1		40·6	46·4	
Mown twice a year ..	49·6	47·6		34·6	43·9	
S.e. of mean	1·25	1·32		2·22	2·39	

there were three instances when the unstacked soil from one ley produced heavier seedlings than soil from other leys, viz. soil B (21% clay) from the cocksfoot plus fescue ley produced heavier tomato and antirrhinum seedlings, and soil C from the cocksfoot and the cocksfoot plus fescue leys produced heavier tomato seedlings. When stacked soil was used, heavier tomato seedlings were produced in mixtures containing soil C from the cocksfoot ley than in mixtures containing soil from the other leys. There were no other significant differences in growth due to the use of soil from one ley rather than another.

Unstacked soil from plots mown regularly produced heavier tomato seedlings in potting mixtures containing soils B and C, and lighter antirrhinum seedlings in mixtures containing soil C, than soil from plots mown twice a year. When stacked soil was used, the growth differences due to this cause were negligible.

Differences in growth caused by using soil from leys sown at different rates were negligible.

In soil from the bare fallows.

Comparison with growth in soil from the leys. When used for potting, soil from the bare fallows produced lighter antirrhinum seedlings with soil A (18% clay) and lighter tomato seedlings with soil C than did soil from the leys.

TABLE VII.

Germination in seed soils and mixtures containing soil C from different leys (angular transformations of germination percentages).

	Antirrhinum			Primula		
	Not stacked	Stacked		Not stacked	Stacked	
	Mixed with peat and sand		Soil only	Mixed with peat and sand		Soil only
Ryegrass	45·2	59·8	58·8	45·4	30·3	17·6
Cocksfoot	50·1	57·8	61·5	52·7	23·6	14·6
Timothy	53·5	59·5	58·2	50·2	22·1	20·9
Fescue	55·3	64·4	54·4	43·3	33·3	18·8
Cocksfoot plus fescue ..	42·7	60·1		43·2	27·7	
Bare fallow	67·7	64·5	56·1	53·4	27·7	10·0
Old grass	61·0	62·7	55·9	53·6	23·3	25·3
S.e. of mean	6·61	3·60	3·60	3·76	4·27	4·27
High sowing rate ..	50·0	58·4		53·1	23·2	
Low sowing rate ..	49·2	60·0		45·7	27·5	
Mown regularly ..	47·9	61·4		49·9	25·9	
Mown twice a year ..	51·3	57·0		49·0	24·7	
S.e. of mean	3·21	1·47		1·53	1·74	

TABLE VIII.

Growth (fresh weight in gm.) in potting soils and mixtures containing soil A from different leys.

	Tomato			Antirrhinum		
	Not stacked	Stacked		Not stacked	Stacked	
	Mixed with peat and sand		Soil only	Mixed with peat and sand		Soil only
Ryegrass	10·0	11·1	9·4	10·2	9·4	3·4
Cocksfoot	10·3	11·4	9·7	10·5	9·4	4·1
Timothy	10·4	10·9	9·9	9·9	9·2	3·6
Fescue	10·0	11·8	10·0	9·9	9·1	4·9
Cocksfoot plus fescue ..	10·3	11·4		9·9	9·1	
Bare fallow	9·8	11·1	9·4	10·9	9·6	2·9
Old grass	10·3	10·4	9·1	12·1	10·2	5·9
S.e. of mean	0·45	0·47	0·47	0·32	0·44	0·44
High sowing rate ..	10·3	11·0		10·3	8·8	
Low sowing rate ..	10·2	11·1		10·2	8·5	
Mown regularly ..	10·4	11·1		10·4	8·6	
Mown twice a year ..	10·0	11·0		10·1	8·7	
S.e. of mean	0·18	0·19		0·13	0·18	

TABLE IX.

Growth (fresh weight in gm.) in potting soils and mixtures containing soil B from different leys.

	Tomato			Antirrhinum		
	Not stacked	Stacked		Not stacked	Stacked	
	Mixed with peat and sand		Soil only	Mixed with peat and sand		Soil only
Ryegrass	11·5	13·6	11·5	8·0	7·4	5·1
Cocksfoot	11·2	13·1	11·7	8·1	7·4	5·2
Timothy	10·7	13·1	11·7	8·1	7·6	4·7
Fescue	11·2	13·3	12·0	7·9	6·8	4·8
Cocksfoot plus fescue ..	13·5	13·4		8·9	7·2	
Bare fallow	9·7	12·6	11·2	6·2	7·5	5·1
Old grass	14·1	13·4	13·1	9·4	6·4	4·9
S.e. of mean	0·36	0·41	0·41	0·30	0·36	0·36
High sowing rate ..	11·2	13·6		8·1	7·4	
Low sowing rate ..	11·1	13·1		8·1	7·5	
Mown regularly ..	11·5	13·4		8·0	7·7	
Mown twice a year ..	10·8	13·3		8·2	7·2	
S.e. of mean	0·15	0·17		0·12	0·14	

TABLE X.

Growth (fresh weight in gm.) in potting soils and mixtures containing soil C from different leys.

	Tomato			Antirrhinum		
	Not stacked	Stacked		Not stacked	Stacked	
	Mixed with peat and sand		Soil only	Mixed with peat and sand		Soil only
Ryegrass	10·6	14·8	14·7	7·9	14·6	13·1
Cocksfoot	12·8	15·3	14·6	8·8	14·2	11·8
Timothy	11·1	13·7	14·4	7·2	14·3	11·2
Fescue	11·2	13·8	14·3	9·6	14·1	12·6
Cocksfoot plus fescue ..	12·9	13·8		9·4	14·7	
Bare fallow	13·5	14·3	13·1	9·9	14·0	12·7
Old grass	11·5	15·0	14·9	10·2	15·4	15·1
S.e. of mean	0·43	0·50	0·50	0·49	0·49	0·49
High sowing rate ..	11·5	14·8		7·7	14·1	
Low sowing rate ..	11·5	14·4		8·2	14·5	
Mown regularly ..	12·3	14·5		7·0	14·4	
Mown twice a year ..	10·7	14·7		8·9	14·2	
S.e. of mean	0·18	0·20		0·20	0·20	

Except with soil B, mixtures containing soil from the bare fallows produced as heavy seedlings as mixtures containing soil from the leys. Even with soil B such differences were not significant when the mixtures contained stacked soil.

Comparison with growth in soil from old grassland. For use in potting soils, soil from the bare fallows on all three soils produced lighter seedlings than soil from old grassland.

Used in potting mixtures, unstacked soil from the bare fallows on soils A and B produced lighter seedlings than soil from old grassland. When stacked soil was used, such a difference only occurred with antirrhinum seedlings in soil C.

Potting mixtures generally produced heavier seedlings than potting soils. This was particularly noticeable with antirrhinum seedlings which were grown for about two months. Tomato seedlings were grown for about one month. With soil C, tomato seedlings grown in potting soils were as heavy as those grown in mixtures and the average weight of seedlings of both tomato and antirrhinum was higher than in the other two soils. It might be that growth was becoming limited in the mixtures. As the potting soils, which were not diluted with 42% of peat and sand, would have a higher initial nitrogen content than the mixtures, it is suggested that nitrogen might have been the limiting factor.

It will be noted that mixtures or soils which increase germination do not necessarily increase growth, and that mixtures or soils suitable for one species are not always so suitable for another.

When the suitability of ley soils for use in John Innes composts is being considered the grass species sown, the rate of sowing and the mowing procedure seem unimportant. In fact, growth and germination in seed and potting mixtures containing soil from bare fallows was similar to that in mixtures containing soils from four-year leys, or even soil from old grassland. This similarity in germination and growth was particularly noticeable when the soil was stacked and the mixtures prepared as recommended for John Innes composts (Lawrence and Newell, 1952). It seems that, in such mixtures, the physical and chemical condition is so improved by the addition of peat and sand, the soil-stacking process, and the addition of fertilizers, that differences between bare fallow, four-year ley, and even old grassland soils become unimportant.

SUMMARY.

Four-year leys were grown on three soils with different mechanical analyses. There were no important differences in nitrate plus ammonia content, or in aggregate stability, of samples taken from the different leys on any one soil. The effects of sowing rate and mowing procedure were also unimportant.

There were large differences in the nitrate plus ammonia content after soil sterilization, and in aggregate stability, between soil samples taken from the leys and those taken from bare fallows on the same soil.

When seed and potting mixtures were prepared as recommended for the John Innes composts (Lawrence and Newell, 1952), germination and growth in mixtures containing soil from the bare fallows was equal to that in mixtures containing soil from the four-year leys. It was even comparable to that in mixtures containing soil from under grass which had been growing for over ten years.

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THE IRRIGATION OF EARLY SUMMER CAULIFLOWER IN RELATION TO STAGE OF GROWTH, PLANT SPACING AND NITROGEN LEVEL

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In previous papers it was shown that early summer cauliflower plants required frequent irrigation, both during the seedling stage of growth and in the field, to produce maximum yields (Salter, 1959, 1960b). However, in commercial practice it is desirable to irrigate as infrequently as possible and to economize in the quantity of water used. In attempts to reduce the number of irrigations to a minimum, but without diminution of marketable yield, increasing attention has been paid by workers in many countries to determining the particular periods during the growth of a crop when a high level of soil moisture is required, or conversely, to determining when irrigation is unnecessary. In two of the experiments described in this paper the water requirements of the early summer cauliflower crop in the field have been investigated.

In addition, the effect of irrigation treatments on the growth and yield of this crop at different plant spacings and nitrogen levels was examined, since it is well known that the yield of irrigated crops may be influenced by the level of soil fertility, by plant spacing and other factors, and it is unlikely that any one irrigation treatment will be the optimum for different levels of fertility and plant spacing.

Methods.

Soil.

The experiments were sited on light sandy loam overlying mixed sands and gravels on an area of the sandy phase of the Newport Series. The available water content of the top 2 feet of soil at field capacity was approximately 3·5 inches.

Cultural details.

Seed was sown in September of the year preceding the experiment and the seedlings were pricked out into pots. After over-wintering in cold frames the plants were planted in the field during March and were then treated as for a normal commercial crop, except for the treatments specified. In Experiments 1 and 2 all plots received the normal base dressing of a compound fertilizer.

Irrigation control.

A method based on that of Penman (1948) was used to calculate the daily potential evapo-transpiration from meteorological data, and has been described elsewhere (Winter *et al.*, 1959). As the soil dried out and approached the maximum

limit of drying for the treatment, gravimetric determinations of the moisture content of samples were made to check the calculated soil moisture deficit. When the desired degree of drying out had been reached the plots were irrigated. All plots received rainfall.

Plant measurements during growth.

In Experiments 1 and 2 the leaf area of the plants was estimated at intervals by the use of linear regressions of leaf area on leaf dimensions determined separately for each treatment. Two plants chosen at random from each plot were measured in Experiment 1 and five plants in Experiment 2. New regressions for each treatment were determined on each occasion and, where individual regressions for each treatment did not differ significantly, a common regression was used to determine leaf area.

Plant measurements at harvest.

The same person judged when each curd was ready for cutting and a record was made of untrimmed fresh weight of each plant, its curd size and quality. Plants were classed as marketable if the curds were 3·3 inches or above in diameter and of good quality. In addition, the leaf area of all plants harvested in Experiments 1 and 2 was measured.

EXPERIMENT 1, 1959.

The object of the experiment was to determine whether moisture-sensitive periods existed for this crop after it was planted in the field. The period from planting until harvesting was divided into two physiological growth phases, the pre-curd and post-curd initiation phases. The stage of curd initiation and its determination has been described in a previous paper (Salter, 1960a). In the present experiment 75% of the plants had initiated curds by 21st May, i.e. six weeks after planting and seven weeks before the mean cutting date. The two growth phases, therefore, were of almost equal duration.

During each growth phase different irrigation treatments were given, the plants being irrigated either when a certain percentage depletion of available water (PDAW) in the depth of rooting, or a given soil moisture deficit (SMD), was reached. Except for one treatment (w_7), sufficient water was given at each irrigation to restore the soil to field capacity. Some of the treatments used were chosen in the light of previous results (Salter, 1959), while others were considered to be commercially practicable.

The eight treatments (see Table I) were replicated five times in a randomized block layout. Each plot contained twenty experimental plants and was surrounded by a guard row of plants. The spacing distance was 24 in. × 18 in. and the variety used was Finney's 110.

Results.

The growth and cropping records under the various treatments are summarized in Table I.

Ample rainfall prevented the accumulation of a soil moisture deficit exceeding 0·5 in. during the pre-curd initiation phase and there was no effect of irrigation

TABLE I.

Treatments and growth data at harvest (mid-June); means of 100 plants.

	Treatments			Growth data		
	Pre-curd initiation phase*	Post-curd initiation phase*	Total irrigations	Total water applied (in.)	Untrimmed fresh weight (gm.)	Curd diameter (in.)	Leaf area (sq.cm.)
w_0	Rain only, 2·50 in. (0)	Rain only, 1·52 in. (0)	0	0·00	959	4·5	4,432
w_1	25% PDAW (2)	25% PDAW (6)	8	3·87	1,406	5·0	8,149
w_2	25% PDAW (2)	Rain only (0)	2	0·64	1,003	4·5	4,533
w_3	Rain only (0)	25% PDAW (6)	6	3·23	1,569	5·3	8,987
w_4	0·5 in. SMD (0)	1·0 in. SMD (2)	2	2·00	1,350	4·9	6,496
w_5	0·5 in. SMD (0)	0·5 in. SMD (6)	6	3·00	1,657	5·3	7,879
w_6	1·0 in. SMD (0)	1·0 in. SMD (2)	2	2·00	1,241	4·8	5,803
w_7	Rain only (0)	Rain only until start of harvest, then 1·0 in. water weekly if SMD not less than 1·0 in. (1)	1	1·00	1,293	5·1	5,655
L.S.D. treatment means, P = 0·05					237	0·34	1,169

* Treatments set out in these columns are those which were *planned* to be given, but natural rainfall made some of them unnecessary. Irrigations *actually* applied are shown by the figures in brackets.

during this phase (treatments w_1 and w_2) on the leaf area of the plants at curd initiation. However, as the soil moisture deficit increased in the post-curd initiation phase in May and June, irrigation during this period greatly influenced the growth and yield of the plants. Plants which received only rain (w_0 and w_2) were significantly smaller than those from all the other treatments. The most frequently irrigated plants (w_1, w_3 and w_5) had the largest leaf area, fresh weight and curd size, while less frequently irrigated plants (w_4, w_6 and w_7) produced somewhat smaller plants and curds. However, it should be noted that a single irrigation of one inch of water, applied just before cutting started (w_7), significantly increased the mean head weight and curd size of the plants compared with those unirrigated (w_0). This treatment, which increased the mean curd diameter by 0·6 inch, could be regarded, therefore, as economically the soundest, for although a slightly larger curd was obtained when the SMD was not allowed to exceed 0·5 inch at any time (w_5), six irrigations were needed to achieve this result.

Neither earliness nor percentage of marketable curds was significantly affected by any of the treatments.

EXPERIMENT 2, 1959.

The effect of frequent irrigation on the growth and yield of plants of the variety All The Year Round grown at different spacings was investigated with the following experimental treatments:

Irrigation.

Treatments w_0 and w_1 as in Experiment 1.

Plant density.

Treatments d_1, d_2, d_4 and d_5 at planting distances 34 × 34, 24 × 24, 17 × 17, and 12 × 12 inches, respectively. These distances were chosen to give a plant density ratio of 1:2:4:8 (a geometric series) covering the range found in practice.

A randomized split-plot layout was used, the main plots for irrigation treatments being split into four sub-plots for plant density treatments. There were five replications and each sub-plot contained twenty-four experimental plants surrounded by a guard row of plants at the same density.

Results.

The increase in leaf area of plants under treatments d_1, d_4 and d_5 is shown in Fig. 1. For the sake of clarity the growth curves for treatment d_2, which are intermediate between those of d_1 and d_4, have been omitted. By the end of May there was little difference in leaf area of the plants grown under the two irrigation treatments but there was a tendency towards poorer growth with irrigation at the closer spacings. However, by the middle of June (a week before cutting started) there was a general decline in the rate of leaf area increase of plants without irrigation, but with irrigation a decline occurred only at the two closest spacings. At this time the mean leaf area per plant was reduced progressively by closer spacing, irrespective of the irrigation treatments. It was obvious during the later stages of growth that nitrogen supply had become a limiting factor at the closest spacings, for symptoms of nitrogen deficiency were present on many of the plants given treatments d_4 and d_5, irrespective of the irrigation treatment. No attempt was made to correct the deficiency. The experimental results must be examined, therefore, with the knowledge that nitrogen deficiency may have influenced growth at the closest spacings.

The mean fresh weight and curd size of all plants per treatment is shown in Table II.

Irrigation increased the plant fresh weight at all spacings. Increases in curd size, resulting from irrigation, were consistent, but less marked than those in fresh weight. Only with treatment d_4 was the increase in curd size statistically significant.

The spacing treatments significantly affected both fresh weight and curd size of the plants, and there was a significant interaction between the irrigation and spacing treatments as shown in fresh weight but not in curd size.

All treatments influenced the percentage of marketable plants and the results are shown in Table III.

Spacing and irrigation significantly influenced the percentage of curds that were marketable from each treatment. The percentage increased progressively with wider spacing and with irrigation. A high proportion of the unmarketable curds was

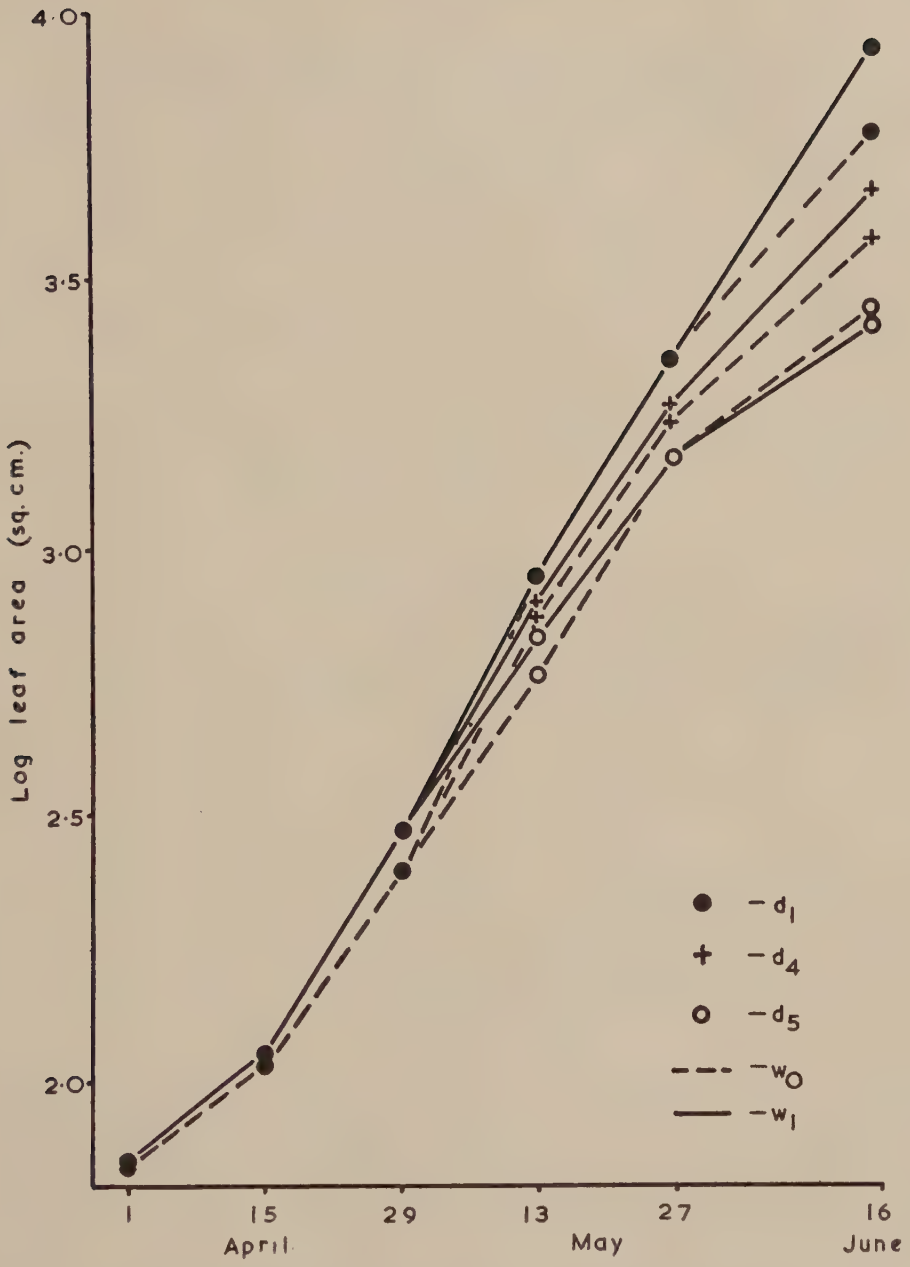

FIG. 1.

Increase in mean leaf area per plant under each treatment; means of 25 plants. Experiment 2.

TABLE II.

Untrimmed fresh weight (gm.) and curd size (in.) per plant at harvest (late June); means of all 120 plants, marketable and unmarketable.

Irrigation treatment		Plant density treatment				Means
		d_1	d_2	d_4	d_5	
w_0	fresh wt.	1,666	1,219	566	287	935
	curd size	5·8	5·1	3·4	2·6	4·2
w_1	fresh wt.	2,034	1,386	716	393	1,132
	curd size	6·0	5·2	3·7	2·8	4·4
Means		1,850	1,303	641	340	
		5·9	5·1	3·5	2·7	

L.S.D. (P = 0·05) for comparisons within the body of the table = 132 and 0·29
,, ,, ,, ,, of irrigation treatment means = 66 and 0·25
,, ,, ,, ,, ,, density treatment means = 93 and 0·17

TABLE III.

Percentage of plants giving marketable heads, minimum curd size 3·3 in. in diameter; transformed figures in brackets.

Irrigation treatment	Plant density treatment				Means
	d_1	d_2	d_4	d_5	
w_0	84·7 (67·8)	65·6 (54·2)	28·6 (32·2)	2·0 (5·1)	45·2 (39·8)
w_1	92·0 (74·0)	64·9 (54·1)	47·4 (43·4)	7·1 (13·9)	52·9 (46·4)
Means	88·4 (70·9)	65·3 (54·2)	38·0 (37·8)	4·6 (9·5)	

L.S.D. (P = 0·05) for figures after angular transformation:
for comparisons in the body of the table = 9·3
,, ,, of irrigation treatment means = 4·6
,, ,, ,, density treatment means = 6·5

smaller than the minimum size limit of 3·3 inches while the remainder were rejected because of their poor quality. The mean fresh weight and curd size of the marketable plants are given in Table IV. The number of marketable plants from the closest spacing treatment (d_5) was so small (many plots having none at all) that the error variance was very different from that of the other spacing treatments. This treatment, therefore, was omitted from the analysis and the L.S.D.'s in Table IV refer only to comparisons within treatments d_1, d_2, and d_4.

The results were similar to those in Table II in showing a very significant positive response to increased spacing and a smaller, but still statistically significant, positive response to irrigation.

There was no significant effect of the treatments on the earliness of the plants.

TABLE IV.

Mean untrimmed fresh weight (gm.) and curd size (in.) of the marketable plants.

Irrigation treatment		Plant density treatment			Means	
		d_1	d_2	d_4	d_1, d_2 & d_4	d_5
w_0	fresh wt.	1,681	1,272	711	1,221	358
	curd size	5·7	5·2	4·1	5·0	3·8
w_1	fresh wt.	2,048	1,492	798	1,446	634
	curd size	6·0	5·4	4·2	5·2	3·9
Means		1,865	1,382	755		496
		5·8	5·3	4·1		3·8

L.S.D. (P = 0·05) for comparisons within the body of the table = 174 and 0·28
,, ,, ,, ,, of irrigation treatment means = 100 and 0·16
,, ,, ,, ,, ,, density ,, ,, = 123 and 0·20

EXPERIMENT 3, 1960.

The results of the previous experiment indicated that the availability of soil nitrogen could be limiting where plants were very closely spaced. In this experiment, therefore, three rates of application of nitrogenous fertilizer were used and were combined with different plant spacings and irrigation treatments in a factorial layout. The various treatments were as follows:

Irrigation:

w_0, plants received rain only.
w_6, irrigated at maximum SMD of 1·0 in. from planting to harvest time.
w_7, rain only until start of harvest, then 1·0 in. irrigation weekly during harvest period if SMD not less than 1·0 in.
w_8, during the pre-curd initiation phase, plants irrigated at 0·5 in. SMD; no further irrigation until start of harvest when 1·0 in. of water given if SMD not less than 1·0 in.

Plant density:

d_1, planting distance 34 × 34 inches.
d_2, ,, ,, 24 × 24 ,,
d_3, ,, ,, 21 × 21 ,,
d_4, ,, ,, 17 × 17 ,,
d_5, ,, ,, 12 × 12 ,,

Nitrogen:

n_0, base fertilizer only (10 cwt./acre compound fert.; analysis, 10% N, 10% PO_5, 18% K_2O).
n_1, base fertilizer plus 5 cwt./acre of Nitrochalk (15·5% N) as top dressing.
n_2, base fertilizer plus 10 cwt./acre of Nitrochalk as top dressing.

In order to reduce the size of the experiment and to examine the combination of treatments likely to be of practical importance, only nine of the possible fifteen n × d treatment combinations were used at each level of irrigation. These are shown diagramatically in Fig. 2.

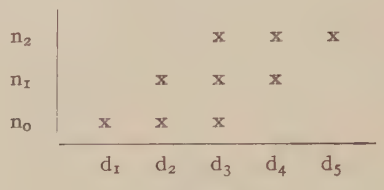

FIG. 2.

Treatment combination of n and d at each level of irrigation.

The nine nitrogen × density treatments at each of the four levels of irrigation gave a total of 36 treatments and there were two replications in a randomized block layout. The number of experimental plants per plot for density treatments d_1, d_2, d_3, d_4, d_5 were respectively 16, 25, 36, 49 and 49, the size of sub-plots having been varied with the different density treatments. Each plot was surrounded by a guard row of plants at the same spacing.

For treatment n_1, top dressings of Nitrochalk were given in two applications of $2\frac{1}{2}$ cwt./acre at 4 and 6 weeks after planting. Top dressings for n_2 were given in four applications of $2\frac{1}{2}$ cwt./acre at 4, 6, 8 and 10 weeks after planting.

RESULTS.

Plants of treatments w_6, w_7 and w_8 were irrigated 2, 2 and 4 times and received a total of 2·00, 2·00 and 2·50 inches of irrigation water, respectively, together with 2·76 inches of rain which fell during the experimental period. The differences in plant response to these three irrigation treatments were non-significant and were small enough to allow a mean figure for the three treatments to be used for comparisons with the unirrigated control (w_0) in the tables of results.

The mean untrimmed fresh weight and curd size per plant for each treatment, taking both marketable and unmarketable plants, is given in Table V. At each plant density except d_1 the mean fresh weight per plant was increased and a larger curd was produced with irrigation. The irrigation treatment means were significantly different.

There was a progressive increase in mean fresh weight and curd size with increase in plant spacing irrespective of the irrigation treatment, but nitrogen top dressings on the whole did not increase fresh weight or curd size.

Irrigation very significantly increased the number of marketable plants (Table VI) and had an increasingly beneficial effect as plant density increased, so that even at the highest density of planting 60% of the plants were marketable. Without irrigation, however, increasing plant density caused a progressive reduction in the number of marketable plants, down to 6% with treatment d_5. At the highest density of planting, therefore, irrigation resulted in a tenfold increase in the number of marketable plants. In general, nitrogen top dressings had no beneficial effect on the proportion of plants that were marketable.

TABLE V.

Untrimmed fresh weight (gm.) and curd size (in.) per plant; means of all plants per treatment, marketable and unmarketable.

Irrigation treatment	Nitrogen treatment	Plant density treatment					Mean of irrigation treatment
		d_1	d_2	d_3	d_4	d_5	
w_0	n_0 fresh wt.	1,352	884	635			
	n_0 curd size	4·7	4·0	3·6			
	n_1 fresh wt.		727	711	499		697
	n_1 curd size		3·7	3·5	3·0		3·5
	n_2 fresh wt.			706	477	287	
	n_2 curd size			3·5	3·0	2·5	
Mean of w_6, w_7 and w_8	n_0 fresh wt.	1,260	1,211	1,046			
	n_0 curd size	4·6	4·5	4·4			
	n_1 fresh wt.		1,178	1,156	782		993
	n_1 curd size		4·5	4·6	4·0		4·3
	n_2 fresh wt.			1,068	748	488	
	n_2 curd size			4·5	4·0	3·5	

L.S.D. (P = 0·05) for comparisons within treatment w_0 = 351 and 0·56
,, ,, ,, ,, ,, treatments w_6, w_7, w_8 = 202 and 0·32
,, ,, ,, ,, between irrigation treatments in body of the table = 286 and 0·46
,, ,, ,, ,, of irrigation treatment means = 95 and 0·15

TABLE VI.

Percentage of plants giving marketable heads; figures in brackets as in Table III.

Irrigation treatment	Nitrogen treatment	Plant density treatment					Mean of irrigation treatment
		d_1	d_2	d_3	d_4	d_5	
w_0	n_0	100·0 (100·0)	92·5 (83·6)	59·5 (50·6)			
	n_1		78·0 (62·1)	53·0 (46·7)	26·5 (30·5)		54·0 (50·9)
	n_2			53·0 (46·9)	17·5 (24·8)	6·0 (13·3)	
Mean of w_6, w_7 and w_8	n_0	97·0 (90·9)	93·3 (81·5)	98·0 (91·9)			
	n_1		99·3 (96·4)	99·5 (96·7)	90·2 (72·5)		90·3 (81·9)
	n_2			96·5 (84·7)	88·0 (71·6)	60·0 (51·2)	

L.S.D. (P = 0·05) for comparisons within treatment w_0 = 23·7
,, ,, ,, ,, ,, treatments w_6, w_7 and w_8 = 13·7
,, ,, ,, ,, between irrigation treatments in body of the table = 19·4
,, ,, ,, ,, of irrigation treatment means = 6·5

The mean fresh weight and curd size of the marketable plants were similar to the means of the combined marketable and unmarketable plants and were only appreciably altered where the treatment resulted in a low proportion of the plants being marketable (treatments d_4w_0 and d_5w_0).

TABLE VII.

Yield of marketable untrimmed heads, tons per acre.

Irrigation treatment	Nitrogen treatment	Plant density treatment					Mean of irrigation treatment
		d_1	d_2	d_3	d_4	d_5	
w_0	n_0	7·23	9·09	6·23			5·24
	n_1		6·20	6·14	3·47		
	n_2			5·57	2·26	0·98	
Mean of w_6, w_7 and w_8	n_0	6·66	12·23	14·39			13·38
	n_1		12·25	16·07	15·24		
	n_2			14·57	14·41	14·60	

L.S.D. ($P = 0·05$) for comparisons within treatment w_0	=	3·27
,, ,, ,, ,, ,, treatments w_6, w_7 and w_8	=	3·68
,, ,, ,, ,, between irrigation treatments in body of the table	=	2·62
,, ,, ,, ,, of irrigation treatment means	=	0·88

The results are presented in terms of marketable yield per acre in Table VII. With irrigation the yield level was held fairly constant at all densities from d_2 upwards and was higher than that of the unirrigated controls. With no irrigation, increasing the density of planting beyond d_2 produced a progressive decrease in yield.

Under the conditions of the experiment, and with the combination of plant spacing and level of nitrogen top-dressing used, there was a tendency for extra nitrogen to depress the yields slightly, with the exception of treatment d_3n_1 receiving irrigation.

Yield response in terms of crates per acre.

By using the data on curd size, it was possible to group the marketable curds into the following size grades: $3\frac{1}{4}$ to $4\frac{1}{4}$, $4\frac{1}{4}$ to $5\frac{1}{4}$, $5\frac{1}{4}$ to $6\frac{1}{2}$, and larger than $6\frac{1}{2}$ in., corresponding to 30, 24, 16 and 12 heads per crate, respectively. The yields in terms of total number of crates of all grades are given in Table VIII and show a somewhat different response pattern to that in Table VII.

The main difference between the response patterns shown in Tables VII and VIII occurred with the irrigated treatments. The yields, in tons per acre, for spacing treatments d_3, d_4 and d_5 were fairly similar, whereas the yields in crates per acre showed a marked trend towards increasing with closer spacing. These differences resulted from two causes. First, as the plant spacing was reduced, the mean weight and curd size of the plant became progressively smaller (Table V) and thus there was a progressive increase in the number of small curds per acre. Secondly, under the conditions of this experiment, a crate containing a large number of small heads weighed less than one containing a small number of large heads.

Table VIII.

Yield in crates per acre.

Irrigation treatment	Nitrogen treatment	Plant density treatment					Mean of irrigation treatment
		d_1	d_2	d_3	d_4	d_5	
w_0	n_0	296	367	306			254
	n_1		292	306	192		
	n_2			286	148	89	
Mean of w_6, w_7 and w_8	n_0	284	444	554			604
	n_1		476	629	767		
	n_2			565	729	991	

DISCUSSION.

Many workers have found that rain or irrigation may be more beneficial to the plant at some stages of growth than others. This has been found for such different types of crop as corn (Denmead and Shaw, 1960), cotton (Spooner *et al.*, 1958), turnips (Stanhill, 1958) and broad beans (Stolp, 1955). The results of the first experiment reported here support previous findings (Salter, 1959) and have shown that for early summer cauliflower frequent irrigation was required from planting until harvesting, for there was no stage of growth when irrigation could be withheld without loss of yield. Other workers have obtained similar results with this crop, for Fröhlich (1955) found that the soil moisture status must be kept above 80% of field capacity in order to obtain maximum yield, and Bierhuizen and de Vos (1959) noted that the lower yield response to a high soil moisture stress at certain periods of growth was not compensated for by low soil moisture stress at others. These results suggest that there is no period during the growth of this crop in a dry year when irrigation could be withheld without loss of yield.

Although it is not possible to reduce the frequency of irrigation without also reducing yield, it does not follow that frequent irrigation is always justified from the commercial aspect. Thus, it may be necessary to economize in water, labour and equipment, in which case irrigation should be reduced to the minimum consistent with obtaining a worth while return. The first experiment in 1959 showed that the highest yield was obtained when the crop was irrigated six times (w_3) but the treatment which gave the best yield response, in relation to the water consumed, was the single irrigation before harvest (w_7). During 1959, however, the weather was exceptional in that frequent rain after planting enabled the plants to become firmly established without irrigation before dry weather started. For this reason treatment w_8, in 1960, was given to reproduce the soil moisture conditions after planting of treatment w_7 in 1959, and to find whether the beneficial effects of irrigation at harvest would be repeated.

The experiment in 1960 showed that there was little difference between yields of the three irrigated treatments w_6, w_7 and w_8 and again indicated that the single irrigation just before harvest time (w_8) was very beneficial, provided the plants had an adequate supply of moisture after planting to become established. In Germany also, Fröhlich (1955) found that the highest irrigation requirement was in May and

June. This is not surprising since the harvesting period in June coincides with the maximum leaf area of the plants (Salter, 1960a) and the period of greatest potential loss of water caused by meteorological factors. The plants respond quickly to irrigation during this period and Bierhuizen and de Vos (1959) have stated that, in practice, vegetable growers in Holland usually irrigate some crops shortly before harvest in order to obtain high fresh weight yields.

Plant spacing has been shown to modify the response of this crop to irrigation when measured in terms of weight of marketable produce per acre (Table VII). With irrigation there was a decrease in marketable yield per acre at the widest spacing (d_1), but the yields were similar at each of the other spacing treatments. Without irrigation, however, increasing density beyond d_2 produced a progressive decrease in yield. The size of head also became smaller with increased density of planting.

However, when the response of the crop was measured in terms of crates per acre the results showed that, with irrigation, higher numbers of crates of smaller curds were obtained by a progressive reduction in the plant spacing. It is not possible to suggest whether yields in terms of tons per acre or crates per acre should be regarded as the more important, for other factors, such as market preferences for certain size grades and price return per crate, will influence the decision whether to grow large or small curds.

Somos (1953), in Hungary, found that the optimum planting distance for an autumn variety of cauliflower was 40 × 50 cm. (16 × 20 inches) and he too found that an increase in the density of planting reduced head size. No other published work has been found on the interrelations of plant spacing, fertility level and irrigation with this crop, but experiments on a variety of other crops, e.g. cabbage (Vittum and Peck, 1956), potatoes (Howe and Rhoades, 1949) and corn (Lawton and Patino, 1960), have shown that increased yields were obtained by an increase in plant density coupled with an increase in soil fertility and the use of irrigation.

In the third experiment described in this paper there was little influence of nitrogen level on yield, but it should be remembered that the base dressing itself supplied over 100 lb. of nitrogen per acre to an already fertile soil. Only the treatment d_3n_1, together with irrigation, showed an appreciable, but still non-significant, increase in yield attributable to the nitrogen top-dressing.

The results of these experiments have practical implications. They suggest that, provided the plants become established during a showery period, the most economic irrigation treatment on this type of soil would be to irrigate just prior to, or during the harvest period, although it might be necessary to irrigate after planting during a dry period. They indicate also that, with irrigation on soils of high fertility, decreasing the plant spacing tends to give a higher number of crates per acre, but with heads of a smaller size. Where irrigation cannot be provided, there seems to be a possibility of improving head size and quality by increasing the plant spacing.

SUMMARY.

Three experiments are described in which the response of early summer cauliflower plants to irrigation treatments at different stages of growth, different plant spacings and different levels of nitrogen was determined. In general, irrigation improved the yield but irrigation just before harvest time was particularly beneficial in this respect. At the widest spacing used, 34 × 34 inches, irrigation did not increase

yield on a soil of high fertility. With no irrigation, decreasing the spacing decreased the yield; with irrigation, decreasing the spacing decreased the head size and tended to increase the yield in crates per acre, but it had no appreciable effect on the tonnage per acre.

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LIQUID FEEDING OF GLASSHOUSE TOMATOES; THE EFFECTS OF POTASSIUM CONCENTRATION ON FRUIT QUALITY AND YIELD

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The application of fertilizers in solution, either via trickle irrigation equipment or by hose watering, has become increasingly widespread in commercial nurseries during recent years. The use of fertilizers in solution rather than in solid form has much to commend it, particularly with regard to uniformity of application and the relative ease with which nutrients can be applied whenever required. Sometimes regarded as a convenient means of applying periodic top-dressings, liquid feeding is almost certainly best used for providing a steady supply of nutrients as required throughout the growth of the crop.

The development of relatively simple equipment for injection of concentrated nutrient solutions into irrigation lines far outpaced the accumulation of basic information concerning this aspect of plant nutrition. Thus, when the present investigation was being planned, the main sources of background information available were the experience of tomato growers and advisers, together with the recommendations of manufacturers supplying fertilizers either in solution or in readily soluble form. Data relating to the conventional use of fertilizers in solid form were also available, but the applicability of much of this information to liquid feeding of glasshouse crops was uncertain. Under commercial conditions the usage of fertilizers in solution varied widely, ranging from occasional top dressings interspersed with hose watering and superimposed on conventional base dressings to fairly comprehensive schemes for applying both water and nutrients together throughout the growth of the crop. In general the potash/nitrogen ratio of the nutrient solutions tended to be high in the early stages of growth, decreasing later in the season as is commonly the practice with fertilizers in solid form. In many cases the total nutrient concentration of the solutions was relatively high at first, and was reduced subsequently. In contrast, however, a system in which the ratio of nutrients to water remained constant throughout the whole season was employed at the National Institute of Agricultural Engineering (12), the amount of water, and hence of nutrients, at each application being proportional to the incident solar radiation and related to data for the total uptake of nutrients by the tomato crop. Practical suggestions for the preparation and use of concentrated nutrient solutions by commercial growers were compiled by the Ministry of Agriculture in 1957 (9), but were not available at the start of the present trials.

The main nutrients applied in solution are nitrogen and potash, with or without phosphate, and sometimes magnesium. The phosphate status of glasshouse soils is often relatively high, and any necessary application of phosphate can most conveniently be given as a base dressing before planting. Even when centred on only two nutrients, however, a comprehensive investigation of liquid feeding would require

a study not only of nutrient concentration and balance, but also of the changes in these concentrations throughout the growing season as generally introduced in commercial practice. Inclusion of this time factor was considered impracticable in these initial studies, particularly when, so far as was known, the use of trickle irrigation equipment in replicated trials had itself not been fully explored.

Two experiments were accordingly planned, in the first of which was studied the effect of potassium concentration on crop yields and fruit quality, the amounts of nitrogen supplied being fully adequate throughout. The liquid feeds were the sole source of added nitrogen and potash, these nutrients being omitted from the base dressing. The practice, frequently adopted commercially, of using relatively concentrated nutrient solutions in the early stages of growth seemed desirable in the present trial if the plants were to be influenced appreciably by the treatments in the first part of the growing season, particularly in the absence of potash from the base dressing. Four potash/nitrogen ratios were therefore chosen to cover a useful range, the lowest being entirely adequate to prevent any possibility of visual symptoms of potassium deficiency and the highest being somewhat in excess of normal practice without producing excessive salinity. These four potash/nitrogen ratios were kept constant throughout the experiment, the nitrogen concentration being equal in all treatments at any one time; the only change in composition of the solutions was a reduction in the concentration of nitrogen as the season progressed, accompanied by decreasing potassium concentrations at the four chosen potash/nitrogen ratios. The treatments thus consisted of four ranges of potassium concentration rather than fixed concentrations, and for this reason will for convenience be discussed as potash/nitrogen ratios.

Experimental methods.

Layout.

The experiment was sited in the western span of a block of aeroplane-type houses running north-south, the cultivated area being 106 ft. by 14 ft. The plants were set out in two double rows along the centre of the house, with additional single lines at the east and west sides, each plant being beside a heating pipe and spaced at 15-in. intervals along the lines. The double rows of plants were divided into four blocks (north-east, south-east, south-west, north-west), each block being subdivided into four plots within which the four treatments were randomized. The two single lines of plants at the east and west sides each formed a separate block of four plots. All plots contained 18 plants of variety Potentate, of which 14 were recorded. The remaining four plants per plot acted as guards between treatments in the central four blocks; only two guard plants per plot were required in the east and west blocks planted as single lines, and the remaining two spare plants per plot were used in studies of total nutrient uptake. Additional guard plots, numbering eight in all, were planted at the north and south ends of the house. The layout of the plots remained unchanged throughout the experiment, but cumulative effects were reduced by winter flooding.

Irrigation and dilution equipment.

The four concentrated solutions of fertilizer were injected into the water supply by Cameron charge-diluters, specially modified to work at the low flow rates necessitated

by the inclusion of several treatments within a limited cropping area. Each diluter was equipped with its own water-meter for measurement of the amounts of solution applied. The diluted solutions were carried along the house in two sets of four $\frac{3}{8}$-in. bore rubber hoses, from which individual plots were supplied with the appropriate solution via $\frac{1}{4}$-in. bore rubber tubing. Each tomato plant was provided with a trickle irrigation nozzle delivering solution at the rate of about 2 pints per hour as required.

Treatments.

The four nutrient solutions used had potash/nitrogen ratios (K_2O/N) of 1·0:1, 1·5:1, 2·0:1 and 2·5:1. The nitrogen in all four solutions was supplied by a combination of urea and potassium nitrate having a potash/nitrogen ratio of 1·0. The additional potassium required for ratios of 1·5–2·5 was supplied by increasing amounts of potassium sulphate. The four ratios remained constant at all times but, as previously stated, the concentration of nitrogen, although the same in all four solutions at any one time, was reduced as growth proceeded. The concentrations of nitrogen applied during the three years of the trial were as in Table I.

TABLE I.

Concentration of nitrogen in irrigation water.

1957		1958		1959	
Period	p.p.m.	Period	p.p.m.	Period	p.p.m.
13 Mar. — 6 Apr.	267	15 Mar. — 13 May	200	9 Mar. — 22 Apr.	225
8 Apr. — 9 May	235	14 May — 30 Sept.	150	23 Apr. — 28 Apr.	150
10 May — 19 June	200			28 Apr. — 28 Sept.	175
20 June — 8 Aug.	160				
9 Aug. — 7 Oct.	133				

The total volumes of diluted solution per plant during the three years were 31·6, 30·5 and 35·4 gallons for 1957, 1958 and 1959, respectively.

The amounts of potash applied in the four treatments, calculated as cwt. K_2O per acre at a planting density of 14,207, are given in Table II.

TABLE II.

Amounts of potash (cwt. K_2O per acre) applied during the experiment.

Ratio K_2O/N	1957	1958	1959
1·0	7·2	6·1	8·1
1·5	10·8	9·1	12·2
2·0	14·4	12·2	16·2
2·5	18·0	15·2	20·3

The nutrient solutions were applied at frequent intervals whenever the crop required watering, usually daily once the plants were growing strongly. The relatively higher concentrations of nutrient at the start of the season correspond to lower rates

of watering of the young plants. The volume of solution given was the same for all treatments at any one application. An adequate level of phosphate was maintained by annual base dressings of superphosphate. The potassium content of the diluted nutrient solutions was checked by analysis at intervals, and any necessary adjustments made in concentration.

Recording and grading of tomato fruit.

The fruit was picked twice weekly for grading at the commercial stage of ripeness. The main categories were as follows:

Grade A. Fruit of uniform shape and colour.
Grade B. Fruit of uniform colour but rather less regular in shape than Grade A.
Grade C. Fruit showing irregular coloration of any kind.
Grade D. Fruit of highly irregular shape.

In this arbitrary classification grade A corresponded to the " Pink ", " Pink/White " and " White " grades of the Tomato and Cucumber Marketing Board, together with any fruit complying with the present definition, but below the lower size limit of the " White " grade. Similarly grade B corresponded to the " Blue " and " Blue and White " grades of the Board, together with the corresponding undersized fruit. Grade C included all fruit to which the terms " blotchy ", " waxy ", or " greenback " would normally be applied, together with any other obvious irregularity of pigmentation. The latter definition was rigorously applied, and grade C thus included a proportion of fruit which for commercial purposes would have been accepted in better grades. In 1958 and 1959 grade C was sub-divided as C1 and C2 for mild and severe instances of irregular pigmentation respectively; a proportion of fruit graded as C1 would subsequently ripen fairly evenly. In 1959 the total numbers of fruit picked from each plot were also recorded. Further data were also obtained from more detailed grading schemes applied in 1957 and 1959, the results of which are reported in a later section.

Analytical methods.

The potassium content of the nutrient solutions was measured with a flame photometer. Determinations of nitrogen, phosphorus and potassium in leaf samples were based on the method of Cavell (5). Soil samples were extracted with 0·5N-acetic acid for the estimation of potassium by the flame photometer and of phosphate by the molybdenum-blue procedure. Conductivity measurements were made at a water:soil ratio of 2·5:1, and the same suspensions were used for the determination of pH with a glass electrode.

EXPERIMENTAL RESULTS.

The soil in the glasshouse had been cropped for three seasons before the present experiment was started in 1957. Although it had not been steamed, growth during 1957 was very vigorous. In 1958, however, the plants made relatively poor growth and the amounts of fertilizer applied were reduced accordingly. The house was steamed before the 1959 crop and good growth resulted. The appearance of the plants, supported by tissue analysis, indicated that an adequate level of potash for vegetative growth was maintained throughout; no foliar symptoms of potassium deficiency occurred in any year, even at the lowest potash/nitrogen ratio. Foliar

symptoms of magnesium deficiency became more obvious with increasing potash/nitrogen ratio, but spraying with a solution of magnesium sulphate prevented the symptoms from becoming severe. No other differences between treatments were apparent in the vegetative growth.

Crop yields and grading.

The yields and grading of tomato fruit are summarized in Table III, each value being the mean of six replicates. The yield data show a fairly heavy crop, particularly in the first and last seasons of the trial. The results suggest a slight reduction in yield at the higher potash/nitrogen ratios; analysis of variance showed no significant differences between treatments, but in 1958, when the crop was less vigorous and the need for partial sterilization apparent, the regression of crop yield on potash/nitrogen ratio was statistically significant.

The proportions of uniformly coloured fruit of regular shape (grade A) and reasonably regular shape (grade B) increased progressively with increasing potash/nitrogen ratio; the effect was more marked in the second and third seasons, suggesting a cumulative effect of the treatments. The best year with regard to fruit quality was 1958, at which time the plants were making far less satisfactory vegetative growth and it

Table III.

Yields and grading of tomato fruit in relation to potash/nitrogen ratio of liquid feeds.

Year	K_2O/N	Total yield lb./plant	Grading (% by weight)				
			A	B	C1	C2	D
1957	1·0	11·76	9·5	14·6	60·3		15·6
	1·5	12·39	11·6	15·5	57·9		15·0
	2·0	11·90	13·3	16·1	55·0		15·6
	2·5	11·89	15·0	17·9	51·8		15·3
	S.e.*	±0·30	±1·63	±1·19	±2·84		—
	P**	—	0·05	—	0·05		—
1958	1·0	10·32	22·4	27·6	35·7	10·1	4·2
	1·5	10·04	30·5	30·4	30·6	4·8	3·7
	2·0	9·78	34·1	34·9	23·4	3·0	4·6
	2·5	9·60	37·2	33·7	22·9	2·6	3·6
	S.e.	±0·25	±2·45	±1·97	±1·89	±1·19	—
	P	—	0·001	0·01	0·001	0·001	—
1959	1·0	11·83	19·6	19·9	47·2	7·7	5·6
	1·5	11·70	23·1	22·1	43·3	6·1	5·4
	2·0	11·79	25·5	25·8	39·7	3·9	5·1
	2·5	11·64	26·4	27·2	37·2	3·6	5·6
	S.e.	±0·27	±1·71	±1·09	±1·36	±0·79	—
	P	—	0·01	0·001	0·001	0·001	—

* Standard error of the difference of two means; ** F-test.

Table IV.

Regression coefficients relating fruit grading and potash/nitrogen ratio.

Year	Grade (%)	Regression coefficient*	Level of significance (P)
1957	A	+ 3·67 ± 1·03	0·01
	A + B	+ 5·75 ± 1·62	0·01
	C	− 5·68 ± 1·79	0·01
1958	A	+ 9·61 ± 1·55	0·001
	A + B	+ 14·16 ± 1·56	0·001
	C1 + C2	− 14·00 ± 1·45	0·001
1959	A	+ 4·55 ± 1·08	0·001
	A + B	+ 9·68 ± 0·90	0·001
	C1 + C2	− 9·64 ± 1·05	0·001

* Change in percentage of fruit in a given grade per unit change in potash/nitrogen ratio.

was difficult to prevent temporary wilting in bright sunshine despite shading of the house.

The proportion of irregularly coloured fruit decreased significantly with increasing potash/nitrogen ratio in all three seasons, but the most interesting results are those for the severely affected category (C2). In 1958 the proportion of grade C2 fruit at the highest potash/nitrogen ratio was little more than a quarter of that at the lowest.

As an extension of the statistical treatment the linear regression of the fruit-grading results on the potash/nitrogen ratio was studied, the results being summarized in Table IV. These results show the magnitude of the increases in good quality fruit (% A and % A + B) and the corresponding decreases in irregularly coloured fruit (% C) with increasing potash/nitrogen ratio.

The data in Tables III and IV are expressed as percentages of the total graded crop and, in view of the significant reduction in yield at high potash/nitrogen ratios in 1958, the weights of good quality fruit (grades A and B) are shown in Table V. The data show that some increase in weights of grades A and B resulted even up to the highest potash/nitrogen ratio ($K_2O/N = 2·5$) in 1957 and 1959, when the plants were growing strongly, but that the practical limit was reached at $K_2O/N = 2·0$ during 1958, when the overall fruit quality was better and vegetative growth weaker.

In addition to the main grading scheme outlined in the experimental section, supplementary grading schemes were also employed to give further information on fruit size and irregularity of pigmentation. Thus in 1957 all regularly shaped fruit (grade A) from each treatment was sized on a grading machine, and fruit of grade B was graded by hand into the categories of the Tomato and Cucumber Marketing Board. The relative proportions of " Pink " ($2\frac{3}{16}$-3 in. diameter), " Pink/White " ($1\frac{13}{16}$-$2\frac{3}{16}$ in.) and " White " ($1\frac{1}{2}$-$1\frac{13}{16}$ in.) fruit in grade A were unaffected by the potash/nitrogen ratio of the liquid feeds. In grade B the proportion of " Blue and White " size ($1\frac{1}{4}$-$2\frac{3}{16}$ in.) showed a slight increase from 25·2 to 28·5% with increasing potash/nitrogen ratio, and a corresponding decrease from 69·0 to 65·7% in the

TABLE V.

Weights of fruit (lb. per plant) of uniform colour and reasonably regular shape (grades A and B) in relation to potash/nitrogen ratio.*

Year	Potash/nitrogen ratio				Regression coefficient**
	1·0	1·5	2·0	2·5	
1957	2·82	3·31	3·47	3·92	0·69 ± 0·20
1958	5·14	6·05	6·72	6·79	1·13 ± 0·16
1959	4·64	5·32	5·98	6·17	1·10 ± 0·15

* Each value is the mean of six replicates. ** Per unit change in potash/nitrogen ratio.

"Blue" (>$2\frac{3}{16}$ in.) category, but the result is of little or no practical significance. In 1959 the total number of fruits from each treatment was recorded in order to calculate the average fruit weights. Again there was no effect of treatment upon fruit size, the mean weights being 2·17, 2·18, 2·18 and 2·16 oz. for potash/nitrogen ratios of 1·0, 1·5, 2·0 and 2·5, respectively. The improvement in uniformity of fruit colour recorded in Table III was thus achieved without any practical effect on fruit size. It is of course well known that fruit size can be reduced by high salt concentrations, but in the present experiment the range of nutrient concentrations was apparently insufficient to show this.

There was an appreciable effect of potassium concentration upon the regularity of shape of the uniformly coloured fruit, excluding the mainly multilocular fruit of grade D. Thus in 1957 and 1958 (Table III) there was a proportionately greater increase with increasing potash/nitrogen ratio in the percentage of fruit of regular shape (grade A) than of somewhat less regular shape (grade B). This effect was not found in 1959, but is supported by other nutritional studies in progress at this Institute.

In 1959 the effect of the nutrient treatments upon the types of irregularity of fruit pigmentation was studied in greater detail, using a grading scheme with 28 main categories and with additional categories where two types of defect were present on the same fruit. This grading scheme was applied to all the irregularly coloured fruit picked on seven occasions during the season, totalling 2,448 fruits. A short summary of the main results is given in Table VI, expressed as percentages of the total number of fruits graded.

The reduction in percentage of irregularly coloured fruit with increasing potash/nitrogen ratio was due more to an effect on blotchy ripening than on greenback, and in particular to a marked decrease in the proportion of severely affected fruit in the former category. Much of the fruit included in the mild category of blotchy ripening would tend to develop a reasonably uniform colour as ripening proceeded further, and may be due merely to minor differences in rate of ripening rather than to any specific disorder. The proportion of fruit showing greenback in this experiment appeared to depend more on physical than on chemical factors, being greatest for plants adjacent to the glass of the house.

Table VI.

Classification of irregularly coloured fruit in relation to potash/nitrogen ratio in the liquid feeds (1959).

	Potash/nitrogen ratio (K_2O/N)			
	1·0	1·5	2·0	2·5
% Non-uniformly coloured	49·4	44·1	39·3	37·4
% Greenback*	21·8	20·7	18·0	18·9
% Blotchy fruit	18·8	15·7	14·6	12·1
,, sub-divided as mild	11·1	11·2	10·1	10·2
,, ,, ,, ,, severe	7·7	4·5	4·5	1·9
% Waxy fruit	2·3	2·6	1·7	1·0

* Including both green and yellow forms.

Soil and leaf analyses.

The potassium content and pC values of the soil samples taken in early October each year, very shortly after trickle irrigation ceased, are summarized in Table VII. The samples were taken with an auger to a depth of 9 in., one set at the position of the trickle nozzles and the other mid-way between nozzles along the irrigation lines. The data for 1957 are the means of the central four replications, but all six replications were included in 1958 and 1959.

The content of available potash in the soil close to the trickle nozzles increased markedly with the potash/nitrogen ratio of the liquid feeds, reaching high values at the two highest concentrations of potash in the feeds. Samples taken 9–18 in. deep at the nozzle positions during 1958 showed less available potash than in the soil above. Between the nozzles the potash content of the soil remained relatively low, though some accumulation was evident at the two highest ratios during 1959. The results show very steep gradients in the levels of soil potash, since the "between nozzle" samples were taken only 7½ in. from the nozzle positions. In contrast, the pC values measured on samples at the position of the nozzles remained relatively high, but were somewhat lower between the nozzles. Thus, whereas potash accumulated near the nozzles, the concentration of soluble salts indicated by the conventional conductivity test was higher mid-way between the nozzles. Even at the latter position the pC values were relatively high, despite the large amounts of potash applied at the higher potash/nitrogen ratios and the obvious improvement in fruit quality resulting.

The pH values were higher between nozzles and showed little variation, the mean value for the three seasons being 7·5. Lower values were recorded at the nozzle positions, the mean value being 6·4, with two treatments below pH6 during 1959. There was no consistent change in pH with increasing potassium concentration in the liquid feeds. The phosphate content of the soil at the end of the season was lower at the nozzles than between them, probably because of leaching by the nutrient solutions.

In 1957 samples of foliage were taken for analysis from all 24 plots in May and again in June, the fifth leaf from the top of the plants being used. No significant differences were found in the nitrogen and phosphate contents of the oven-dried leaves, but the potash content of the leaves increased with increasing potash/nitrogen

TABLE VII.

Available potash and pC values in soil samples taken at and between irrigation nozzles.

	Potash/nitrogen ratio			
	1·0	1·5	2·0	2·5
% K_2O at nozzles				
1957	0·059	0·077	0·108	0·127
1958	0·058	0·085	0·108	0·130
1959	0·065	0·097	0·115	0·137
% K_2O between nozzles				
1957	0·016	0·014	0·018	0·021
1958	0·015	0·019	0·024	0·031
1959	0·011	0·020	0·033	0·041
pC at nozzles				
1957	3·58	3·52	3·48	3·44
1958	3·68	3·60	3·52	3·54
1959	3·57	3·52	3·47	3·45
pC between nozzles				
1957	3·20	3·15	3·13	3·13
1958	3·47	3·26	3·28	3·20
1959	3·38	3·30	3·28	3·18

ratio at the first date of sampling, and was significantly lower at a ratio of 1·0 than at 1·5 and 2·5 at the later sampling date (Table VIII). The analyses show that, even at the lowest potash/nitrogen ratio, the potassium content of the foliage was well above deficiency level.

TABLE VIII.

Percentage of K_2O in oven-dried leaves from plants irrigated with feeds containing different potash/nitrogen ratios.

Date of sampling	Potash/nitrogen ratio				
	1·0	1·5	2·0	2·5	L.S.D.*
22nd May 1957	6·16	6·34	6·49	6·63	0·33
20th June 1957	5·18	5·94	5·64	5·90	0·65

* Least significant difference at P = 0·05.

DISCUSSION.

Although trickle irrigation is now widely used in commercial glasshouses, the system has rarely been employed for nutritional investigations. Experience gained in the course of this work has shown that the commercial equipment can be used successfully for replicated trials with small plots. The diluters used in this work were specially modified to operate at low flow rates, but comparable equipment is now generally available. The layout of the irrigation equipment for replicated trials

can be relatively complex, but the uniformity of plant growth within the plots was better than that achieved in manurial trials using fertilizers in solid form. Analytical control of the nutrient solutions applied to the plants is essential, and frequent samples should be taken at the nozzles.

The results show that nutrient concentration is an important factor in fruit quality, and that much can be done to reduce the proportion of irregularly coloured fruit by choice of suitable potash/nitrogen ratios. When the plants were making relatively poor growth in unsteamed soil, as in 1958, a potash/nitrogen ratio greater than 2·0 seemed undesirable; at $K_2O/N = 2{\cdot}5$, the total yield was less than at 2·0 without any increase in the weight of uniformly coloured fruit (grades A and B). This suggests that, under these conditions, 12 cwt. of potash (K_2O) per acre was sufficient to give high quality fruit. For more vigorous plants, as grown in 1957 and 1959, it is more difficult to establish an optimum potash/nitrogen ratio from the present data, since some slight improvement in yields of high quality fruit resulted even at a ratio of 2·5:1, corresponding to 18 and 20 cwt. of K_2O per acre in 1957 and 1959, respectively. These are high rates of application, and the possibility of root damage, together with the increased incidence of magnesium deficiency, suggests that some risk to the crop may be involved. The present data are sufficient to justify the use of potash/nitrogen ratios between 2·0 and 2·5, corresponding to some 16–18 cwt. of potash (K_2O) per acre in our trial, for vigorous crops in new or sterilized soil, but further trials would be necessary to establish the upper limit under these conditions. In commercial practice, nutrients would probably be omitted from waterings in the last weeks of growth, thus reducing the amounts of potash applied by 1–2 cwt. per acre.

The amounts of potash applied even at the lowest potash/nitrogen ratio were fully adequate for plant growth, and the improvements in fruit quality reported were achieved with virtually no effect on fruit size.

Whilst there are few published data on the effect of potassium concentration in liquid feeds upon fruit quality, the effect of fertilizers in solid form has been widely investigated for many years. Bewley and White (2) concluded in 1926 that blotchy ripening of tomato fruit was the result of malnutrition in respect of potash and nitrogen, especially the former. The disorder was not entirely eliminated by manurial treatment, however, and other factors, probably climatic in nature, were considered to be operative. Owen (14) reported a marked reduction in the proportion of blotchy fruit by increasing levels of potash. Lamm (13), giving the results of a number of fertilizer trials in southern Sweden, showed that the tendency to blotchy ripening was much reduced at the higher levels of potash. Strømme (16) reported that " potassium sulphate had a large negative effect on the amount of blotchy fruits, and on the occurrence of a type of greenback characterized by a marked boundary of the affected area ". It was concluded that a high potassium level in the soil had a favourable influence on fruit quality. Clay and Hudson (6) showed a reduction in blotchy ripening with increasing levels of soil salinity induced by relatively heavy dressings of a mixture of potassium and magnesium sulphates.

Although the improvement in fruit quality resulting from increasing levels of application of potassium salts is now well supported by experimental evidence, distinction between the direct effects of potassium ions and the accompanying increase in soil salinity still needs further consideration. Thus Kidson and Stanton (11), studying " cloud " or vascular browning of tomatoes in New Zealand, found that the incidence of the disorder was decreased not only by muriate of potash but also by

nitrogenous fertilizers and by calcium chloride. Treatments supplying extra nitrogen and potash together were more effective than those supplying either nitrogen or potash alone. Subsequent reports from the Cawthron Institute (1) have confirmed that nutrient level markedly affects the incidence of cloud, one experiment being quoted as producing twelve times as much cloud at low as compared with high levels of fertilizers supplying both nitrogen and potash. On a visit to this country Kidson identified the symptoms of cloud with the green form of blotchy ripening accompanied by vascular browning. Working with tomatoes in water-culture, she also found that raising the osmotic pressure of the solution by trebling the standard quantity of the major elements or by adding sodium sulphate equivalent to the extra salt concentration reduced the incidence of cloud, the former less effectively than the sodium sulphate treatment (10). Butters (4), studying the pC value of soils and its effect on the tomato crop, included a treatment in which sodium sulphate was used to increase the concentration of the soil solution whilst maintaining an adequate level of the major nutrients. In one year the treatment gave an improvement in uniformity of pigmentation of the fruit comparable with that obtained by increasing the amount of balanced fertilizer (supplying N, P, K and Mg), though in the following year treatment with sodium sulphate was less successful. These results, and those of Kidson using calcium chloride and sodium sulphate, indicate that increasing the soil salinity without supplying any additional potash can improve fruit quality, and it may be that, above the levels of potash necessary for plant growth, any further improvement of fruit quality is a general effect of soil salinity rather than a specific effect of potassium. Potassium is an important constituent of tomato fruit, however, being the predominant cation present. Thus Bradley (3) found that potassium accounted for 85% of the total cations removed by ion exchange from tomato puree, and that increases in the acidity of the fruit were accompanied by substantial increases in the potassium content. Unpublished results at this Institute support those of Bradley, and also show that fruit from potassium-deficient plants is of particularly poor quality with regard both to blotchy ripening and to other defects. It thus appears likely that potassium supply, when inadequate, has a specific effect upon fruit quality, whereas at higher concentrations of potash its effect is due, at least in part, to increased salinity.

The fact that the proportion of irregularly coloured fruit is significantly influenced by manurial levels in no way implies that these ripening disorders are exclusively nutritional problems. The proportion of non-uniformly coloured fruit shows marked variation from year to year, as is at once apparent from results quoted by Bewley and White (2), White (17), Strømme (16) and others. In the present trials the proportion of irregularly coloured fruit was clearly much lower in 1958, when the plants were growing relatively poorly in unsteamed soil. Heavy watering, soil sterilization, fresh organic manures, all of which tended to produce coarse leafy growth, were shown by Kidson and Stanton to increase the incidence of cloud (11). It was observed that cloud was more prevalent in unheated than in heated glasshouses, and was worse in a wet than in a dry season. Closs (7) reported studies in controlled environment cabinets in which cloud or blotchy ripening in tomatoes could be induced at low light intensities, with some indication of an adverse effect of high humidities. Hall and Dennison (8) showed that vascular browning was increased by shading and by keeping the plants moist by use of mist nozzles. Several physical factors thus appear to have a marked effect on ripening disorders of this type.

Apart from blotchy ripening and related browning in the region of the vascular bundles, it is also apparent that environmental factors affect the incidence of greenback, which in the present studies was far more prevalent among fruit from plants adjacent to the exposed side of the glasshouse. Bewley and White (2) considered that the symptoms of the disorder, although influenced by potash and nitrogen deficiencies, were intensified by exposure to strong sunlight.

Certain authors have expressed the view that the role of mineral nutrition in fruit ripening disorders is quite subsidiary. Thus White (17) concluded that ". . . blotchy ripening is not due directly to lack of potassium or nitrogen, but to metabolic changes that are counteracted by increase of light". Seaton and Gray (15) considered that blotchy ripening was due primarily to conditions resulting from the withdrawal of water from fruit during periods of excessive transpiration, and that deficiencies of potash and nitrogen were probably of secondary and occasional interest only.

Much work remains to be done, not only on the environmental factors influencing the various forms of irregular pigmentation and structural abnormality in tomato fruit, but also on the biochemical processes involved. Whatever the mechanism of the various ripening disorders, however, the results of the present investigation show that nutritional levels influence the proportion of irregularly coloured fruit grown under conditions similar to those in commercial nurseries.

The analytical data in Table VII illustrate the difficulty of using soil analysis as a guide to the nutrition of crops grown with trickle irrigation equipment. The nutrient gradients in the soil are so steep that, apart from possible injury to roots by soil-sampling tools, little reliance can be placed on the results obtained. Nutritional control should be based on detailed knowledge of the amounts of fertilizer applied, coupled with the appearance of the crop; soil analysis may well be confined to assessment of nutrient status before planting. Even if representative samples could be obtained, interpretation of the analytical results would need care and further study; even the most saline samples referred to in Table VII showed conventional pC values greater than 3·1, whereas considerably lower values consistently occur for crops of comparable fruit quality in other trials at this Institute in which fertilizers are applied in solid form with hose watering.

SUMMARY.

1. The effect of different rates of application of potassium on yield and quality of glasshouse tomato fruit has been studied for three years, in an experiment using trickle irrigation equipment in a replicated layout to supply both water and nutrients. Four different potash/nitrogen ratios (K_2O/N = 1·0, 1·5, 2·0 and 2·5) were maintained in the nutrient solutions throughout the experiment, the nitrogen content of the four solutions being the same at any one time but decreasing through the season.

2. In only one season out of three, when the plants were growing less vigorously in unsteamed soil, was there a statistically significant reduction of yield with increasing potash/nitrogen ratio.

3. The proportion of irregularly ripened fruit decreased with increasing potash/nitrogen ratio each year. The regression of percentage unevenly ripened fruit on potash/nitrogen ratio was significant at P = 0·01 in the first year and at 0·001 in the second and third years. In the last two years of the trial the unevenly

ripened fruit was sub-classified as either mild or severe; the percentage of severely affected fruit decreased even more markedly with increasing concentration of potassium.

4. In the year in which the plants were growing less vigorously in unsteamed soil, no increase of yield of high-grade fruit resulted at a potash/nitrogen ratio greater than 2·0, corresponding to 12 cwt. of potash (K_2O) per acre in this trial. In the two years when growth was more vigorous, the greatest yield of high-quality fruit was recorded at a potash/nitrogen ratio of 2·5 (18-20 cwt. K_2O per acre), but the increased incidence of magnesium deficiency symptoms suggests that some risk to the crop may be involved in the use of such high rates of application.

5. Soil samples taken at the end of each season showed very steep nutrient gradients in the soil between the nozzles. The content of available potassium was highest at the position of the irrigation nozzles, but relatively low mid-way between adjacent nozzles, that is, $7\frac{1}{2}$ inches away from each nozzle. In contrast, the electrical conductivity of soil suspensions prepared at a water/soil ratio of 2·5:1 was highest between rather than at the nozzles.

6. Even the highest rates of application of potash via trickle irrigation equipment in this trial did not produce salinity levels that would normally be considered excessive.

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THE EFFECT OF RUBBERY WOOD VIRUS ON THE STOOLBED PRODUCTION OF TWO CLONAL APPLE ROOTSTOCKS

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Rubbery wood virus occurs in apples in many parts of the world. In England the disease caused by this virus is of importance in the sensitive variety Lord Lambourne and to a lesser extent in other sensitive varieties such as James Grieve, Miller's Seedling and Golden Delicious. Most varieties, however, are tolerant to this virus, showing no easily recognizable symptoms, although Posnette and Cropley (6) have found that the virus is widespread among the dessert apple varieties grown in this country. It has also been found in cider varieties (2) and in dessert and perry pears.

Luckwill (3) and Posnette and Cropley (6) have shown that some of the clonal rootstocks in general use in England also carry rubbery wood virus; many of the stools of M.I and M.IX that they examined were found to be infected, and other rootstocks had smaller percentages of infection. Luckwill (4) has also shown that the virus content of individual rootstocks varies with their size, a higher percentage of the smaller ones being infected.

Although the serious effects of rubbery wood have been shown in sensitive varieties, little evidence has been presented to show why it is desirable to use only virus-tested material of those varieties and rootstocks that are tolerant to this disease. The effect of rubbery wood on the vigour of tolerant rootstocks was therefore examined in an experiment started in 1953.

Experimental layout and methods.

Eight plots each containing 17 stools of M.VII rootstock and eight plots containing 16 stools of M.I rootstock were planted during the winter of 1953/54. The planting distance of 5 feet between the rows, and 18 inches between stools in the rows, was slightly wider than the normal stoolbed spacing. In addition, each plot was separated from its neighbour by a gap of 3 feet. The rootstocks were taken from stools that had been virus-tested and found free from rubbery wood virus. A uniform grade of rootstock was used, with a diameter of 8-10 mm., measured just above the roots.

In August 1954 the rootstocks in half the plots, selected at random, were inoculated 2 inches above soil level. The inoculation buds were taken from a single tree of Lord Lambourne that was showing typical severe symptoms of rubbery wood virus. The rootstocks on the remaining plots were not inoculated. During the remainder of 1954 all the rootstocks were allowed to grow normally, and no symptoms of any virus were seen on either the inoculated or the control stocks in that period. In the following spring all the rootstocks were cut down to 1 inch above ground level, the normal practice when a new stoolbed is being started. This removed the infected

bud from the inoculated stools, the assumption being made that the virus would by this time have passed into the lower part of the stool.

Subsequently the number and grade of stocks produced by each stool were recorded annually, and from 1958 onwards the total weight of rootstocks taken from each plot was also measured. During this time no abnormal symptoms or obvious signs of rubbery wood were seen.

To confirm that the virus inoculation had been successful and that the infected rootstocks were carrying rubbery wood virus, a random sample of five rootstocks from each plot was lined out in 1957/58 and virus-tested by bud-grafting them with buds taken from healthy Lord Lambourne trees. It was found that all the control stools had remained free from rubbery wood virus, and that all the rootstocks from the inoculated stools, except four, were carrying a virulent strain of the virus. Two of these exceptions were from M.I stools and two from M.VII stools, and a correction to allow for this was made in the analysis of co-variance.

EXPERIMENTAL RESULTS.

M.I and M.VII reacted differently to inoculation with rubbery wood virus. Both proved tolerant in that their rigidity was not affected; their vigour, however, was reduced. M.I was more rapidly and more severely affected than M.VII, and in the fourth year after inoculation the number of rootstocks produced from the infected plots of M.I was approximately one third less than that from the control plots. It will be seen from Figs. 1 and 2 that this difference in productivity has persisted

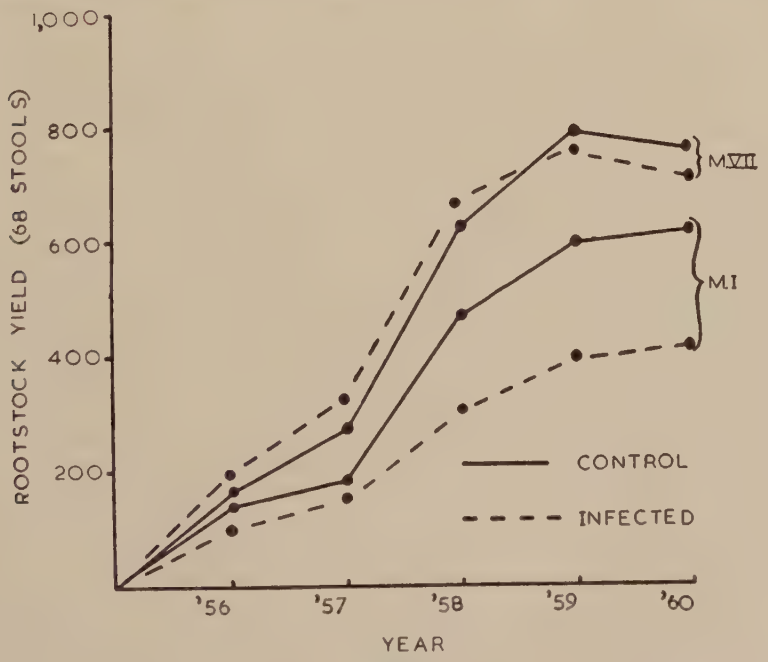

Fig. 1.

Numbers of M.I and M.VII rootstocks taken from rubbery wood infected and control plots during a five-year period.

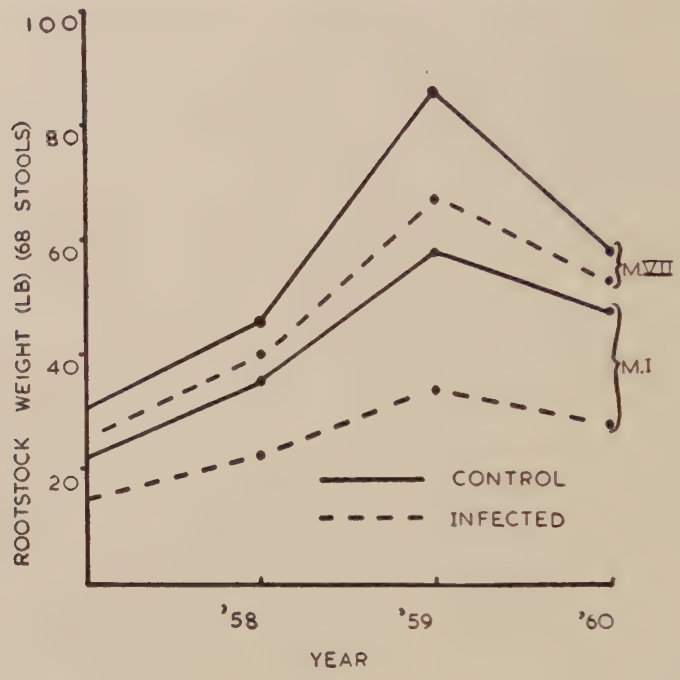

Fig. 2.

Weights of M.I and M.VII rootstocks taken from rubbery wood infected and control plots during a three-year period.

and is reflected in both the number and the weight of rootstocks. The difference has, however, remained fairly steady for the last three years.

By contrast the numbers and weights of rootstocks taken from the inoculated plots of M.VII have remained very similar to those taken from the control plots and only in the last two years has an appreciable, but not significant, reduction been seen. The maximum difference in numbers reached 14% in 1960 and is thus considerably less than the difference between the M.I treatments. If production during the whole period is compared (Table I) it will be seen that the infected stools of M.VII have produced a few more rootstocks than the controls.

Table I shows the total numbers (1956-60) and weights (1958-60) of rootstocks taken from the inoculated plots and the controls and also the numbers and weights taken in 1960. It will be seen that the number produced by the control plots of M.I is significantly higher ($P < 0{\cdot}01$) than that from the inoculated plots. The mean weight is also significantly higher at the same level, although the weight difference in 1960 is significant only at the 5% level.

Fig. 3 shows the size grades of the M.I rootstocks produced by the infected and the control plots, from 1957 to 1960. It will be seen that in each grade the number of rootstocks from the infected stools is less than that from the controls; over the four-year period the percentage reduction is greater in Grade I than in Grades 2 and 3.

TABLE I.

Numbers and weights of apple rootstocks produced from stools with and without rubbery wood virus.

Rootstock		Mean no. per plot		Mean weight per plot (lb.)	
		5 yrs. (1956–60)	1960	3 yrs. (1958–60)	1960
M.I	Infected	315	92	18·6	5·6
	Control	539	165	39·1	14·0
	Sig. diff.	204 (P = 0·01)	41 (P = 0·01)	16·6 (P = 0·01)	8·1 (P = 0·05)
M.VII	Infected	659	169	36·2	12·1
	Control	645	197	49·0	15·1
	Sig. diff.	NS	NS	NS	NS

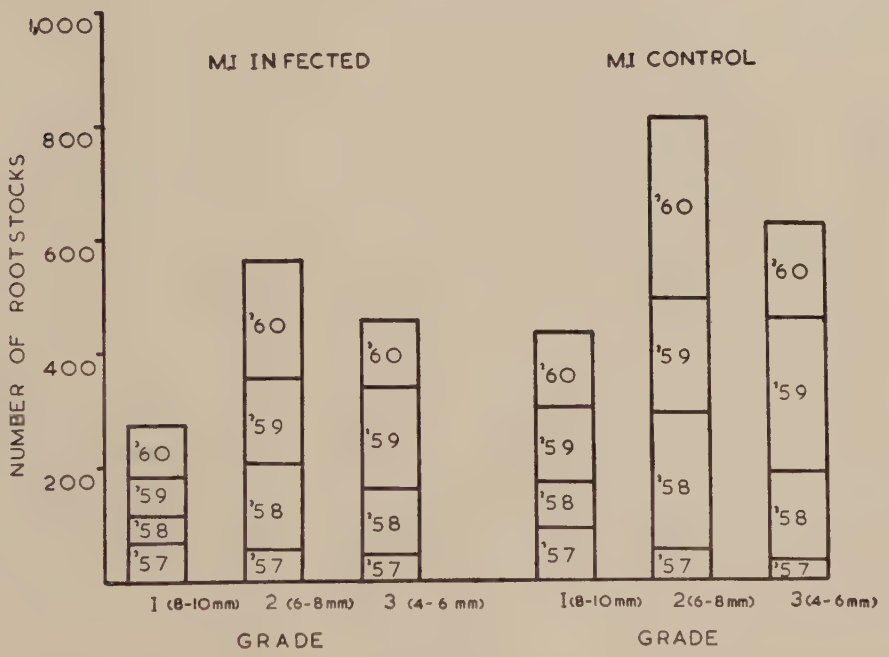

FIG. 3.

Numbers of graded M.I rootstocks taken from rubbery wood infected and control plots during a four-year period.

The numbers of M.VII rootstocks from the infected plots have not been significantly different from those of the controls at any time. In 1960 the infected rootstocks appeared smaller than the controls; this is reflected in the difference between the weights in Table I, which approaches significance. The grading is affected as with M.I, but not nearly so severely.

DISCUSSION.

It is often assumed that a virus producing no symptoms in the host plant will have little effect on the vigour of that plant. However, the present results show that the growth of a so-called tolerant variety can be depressed by virus infection, even though the plant fails to develop typical symptoms of disease. Working with strains of apple mosaic virus, Posnette and Cropley (7) have also reached the conclusion that the development of the virus symptoms may not be the only indication of the severity of the disease.

It is interesting that the effect of rubbery wood has differed on M.I and M.VII and it seems likely that other tolerant rootstocks and varieties may also react in different ways to this virus.

Since the effect of rubbery wood virus is to increase the proportion of the Grade 3 stocks at the expense of the larger grades, this might explain Luckwill's findings (4) that a higher percentage of the smaller rootstocks were infected. In addition, since the larger rootstocks are frequently poorly rooted, they are often rejected by the propagator in favour of the smaller second-grade stocks. The third-grade stocks are usually bedded for use the following year. In this way a larger proportion of the infected rootstocks would be retained and infection would increase.

The reduction in yield from the infected stools of M.I has remained at about the same level for the last three years and there seems no tendency for it to become greater. With M.VII, however, the difference may increase if the present trend continues. It is interesting to note that M.I and M.IX are usually considered to give lower yields than M.II and M.XVI (1). This may be due in part to the effect of rubbery wood virus, M.I and M.IX commonly carrying heavy infection, whereas M.II and M.XVI are generally not infected with this virus.

Although the M.I and M.VII stocks used in this experiment were known to be free from rubbery wood virus, work carried out since the trial started (5) has shown that, in common with most other rootstocks and varieties in this country, they are latently infected with other viruses.

Until it is known whether the rootstocks contain the same latent infection as the Lord Lambourne used for inoculation, it must remain uncertain whether the reduction in yield is wholly due to rubbery wood, or to an interaction between this and one or more of the other viruses carried by the scion or the rootstock. Such a possibility, however, would not modify the main conclusion from this work, which is that latent virus infection of apple can result in an appreciable diminution of vegetative vigour.

SUMMARY.

(1) The inoculation of the clonal rootstock M.I with rubbery wood virus led to a marked reduction in vigour, although no symptoms of rubberiness were observed. The number of rootstocks produced by the infected stools over a five-year period was approximately 60% of that from uninoculated controls; the weight was reduced by a similar amount. There was a marked reduction in the number of large rootstocks produced and a smaller reduction in those of lower grade.

(2) When M.VII was inoculated with rubbery wood virus its rigidity was likewise not affected, but the number and the weight of rootstocks were only slightly reduced.

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SOLUBILIZED NEMATICIDES AND TRICKLE IRRIGATION OF TOMATOES

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It has been shown (Stone, 1956) that solubilized nematicides, used as a soil drench, can give a satisfactory kill of the potato root eelworm (*Heterodera rostochiensis* Wollenw.) under laboratory conditions. In the glasshouse border the degree of kill falls off markedly in the deeper layers of soil. The difficulty is that of reaching the cysts in the soil mass.

However, when tomatoes are fed by trickle irrigation, specialized conditions operate, and I am indebted to Mr. L. J. Hooper for suggesting that this type of material might be put through the irrigation system.

Method.

When tomatoes are fed by trickle irrigation from the time they are put into the glasshouse border, root development is governed by the water and nutrients reaching them from the nozzles (Moorat, 1956). Thus, if the soil is infested by potato eelworm, the new generation of cysts formed on the roots should be reached by a liquid nematicide passed through the system at the *end* of the growing season. This technique was tested in a glasshouse at Banwell, Somerset, in 1957. A batch of 200 plants was treated, 20 of which were known to be heavily infested with potato eelworm. A 2-gallon diluter was filled with nematicide and set to deliver at 1 in 50. Thus, one filling should deliver half a gallon per plant. This was checked by collecting the liquid passed through two of the nozzles. The nematicide used was p-m-cresol (a mixture of equal parts of para- and meta-cresol) solubilized with a detergent of the alkyl-sulphate type. For complete solubilization in the neat form, 75% of the mixture was detergent. Hence the concentration of cresol passing through the nozzles was 0·5%.

The soil in this glasshouse has a very marked crumb structure and liquid applied to it moves downwards with very little lateral spread. Root growth was therefore mainly vertical, and soil samples taken almost vertically with a cheese-corer type of tool 3-9 in. from the main stem passed through the main root zone. Soil samples were taken in the vicinity of infested plants on 24th October 1957, soil from 0-6 in. and 6-12 in. being bulked separately. The plants then each received ½ gallon of nematicide. Further samples were taken on 25th October, and a further ½ gallon of nematicide was applied. Final samples were taken on 30th October; the sampling sites formed a small equilateral triangle in the vicinity of each infested plant.

Cysts extracted from the samples were submitted to potato root diffusate in the Spring and Summer of 1958, the exudate being changed weekly until hatching had virtually ceased.

* Now at S. Wales Sub-Centre, 66 Tyglas Road, Cardiff.

Results.

These are summarized in Table I. Since it was not possible here to have a system of treated and control batches of plants, it must be pointed out that these data are observational only; this is not a controlled experiment. Nevertheless the figures indicate a remarkably high degree of control of potato root eelworm. Had the roots been pulled out in the ordinary way, a high population would have remained in the soil.

Table I.

Effect of p-m-cresol, applied to eelworm-infested tomatoes in irrigation water, on eelworm populations in root zone; soil samples taken from two depths.

Eelworm criteria	Soil sample					
	Before treatment (24th Oct.)		After ½ gallon/plant (25th Oct.)		After 1 gallon/plant (30th Oct.)	
	0–6 in.	6–12 in.	0–6 in.	6–12 in.	0–6 in.	6–12 in.
Cysts/gram	2·5	1·5	2·5	1·7	4·0	1·7
Larvae/cyst	87·2	93·3	1·2	1·7	Nil	·03
Larvae/gram	215	140	2·9	2·9	Nil	·06

Practical considerations.

This type of treatment is aimed at the new generation of cysts produced on tomato roots; it is not comparable to an overall sterilization, which is aimed at the population present in the soil mass as a whole. Nevertheless, at any given time it is the most recent generation which contributes most to the population of potato eelworm present in glasshouse soils; and successive generations are of course responsible for the rapid build-up of population which occurs under continuous tomato cropping.

Further experience on different soil types is required before it could be claimed that this technique alone will provide a commercial control of potato root eelworm. However, growers who use it in the early stages of an eelworm infestation could expect at least a less rapid build-up of eelworm population in the soil, thus delaying the need and expense of general soil sterilization.

Because of the phytotoxic properties of this type of material, it should on no account be used before the end of the growing season.

SUMMARY.

Soil sampling in the vicinity of tomato plants fed by trickle irrigation has indicated that a solubilized nematicide, when passed through the system, can kill a very high proportion of the cyst contents of potato root eelworm formed on the roots.

REFERENCES.

Moorat, A. E. (1956). How trickle irrigation affects roots. Grower, **45**, 35-9.

Stone, L. E. W. (1956). On the control of potato root eelworm (*Heterodera rostochiensis* Wollenw.) by chlorinated phenol and p-m-cresol in solubilised form. Ann. appl. Biol., **44**, 292-306.

(*Received* 20/4/61.)

BOOK REVIEWS

THE PINEAPPLE—BOTANY, CULTIVATION AND UTILISATION. By J. L. Collins. (London: Leonard Hill (Books) Ltd., New York: Interscience Publishers Inc. 1960. Pp. 294, illus. Price 60s.)

The publishers describe this book as a complete guide to the pineapple's history, botany, cultivation and uses and claim it to be the only book needed for its study, cultivation and commercial exploitation.

The first twenty-four pages deal with the early history of the plant, and the author concludes that its cultivation was widespread in central and tropical South America by the 16th century. Extensive quotations are made from the writings of the Spanish explorer Oviedo, and a summary is given of the post-Columbian spread of the plant to St. Helena, Africa and tropical Asia.

Next, there is a first-class account of all botanical aspects of the crop, a description of varieties and their distribution, and an account of its cytology, genetics and breeding techniques, which will be of great value to all plant breeders. Naturally, perhaps, most attention is paid to the Cayenne variety as cultivated in Hawaii, but then, of course, this bias also reflects where most research has been done. However, much of the information which is summarized in the excellent tables has more extensive application.

Part II provides chapters on climate and soil, cultural methods, diseases and pests and environmental influences. The long chapter on cultural techniques is perhaps the least satisfactory in the book, as the descriptions are basically superficial and, even on his home ground in Hawaii, the author makes no attempt to give any fundamental guide to fertilizer practice. Beyond a passing reference to a potash: phosphorus ratio of about 12 to 1 there is no mention of leaf analysis. One looks in vain, both here and in the bibliography, for a reference to the classic 1936 paper by Follett-Smith and Bourne on the uptake of minerals at different stages of growth, and this glaring omission is not even partially filled by reference to later research elsewhere. It is perhaps not the author's fault that the publishers should describe this as " the definitive textbook ", but a chance has been lost to round off this otherwise excellent work by collaboration with a soil chemist and an agronomist. As it is, there is no mention of the important effect of potash on the sugar and acid contents of the fruit.

The importance of the minor elements—iron, zinc and copper—receives brief mention in several sections of the book, but careful search is required for guidance on dosages and concentrations. Certainly a grower might well be stumped, on p. 137, by reference to a spray containing " liquid iron ".

There is a short and interesting section on the use of hormones to initiate flowering and control fruit size and, on p. 148, a most useful chart to illustrate the relationship between plant spacing, within and between rows, and the number of plants per acre after allowance for different proportions of land under roads and ditches. With any three of these data known, the fourth can be read off the chart. Growers in many countries will be grateful for this aid, which does not appear to have been published before.

The important chapter on diseases and pests is valuable in so far as the author deals with Hawaii, but less satisfactory for other countries. Johnston's identification of the causal organism of bacterial heart rot and fruit collapse receives no mention, nor does the green die-back, which is caused by copper deficiency on the peat soils of Malaya. There appears to be a heading missing, or perhaps more, on p. 195, as we find ourselves dealing with insect pests in South Africa under the heading " Fruitlet core rot ".

It seems wrong that it is only in the short chapter on the influence of environmental factors, in a section on salt water spray damage, that we find a reference to leaf damage by chlorine, and it is to be hoped that growers will infer from this that potassium chloride is an unsuitable fertilizer.

Part III, on utilization, contains short chapters on cannery techniques and other methods of preservation and on by-products. The general reader will find all this of interest, but the food technologist will look in vain for any reference to the preparation of juice concentrate by low temperature evaporation.

Finally, there is a short and interesting appraisal of the future of the pineapple industry, and demographic evidence is quoted for the conclusion that two-thirds of the present world population can be eliminated as possible future purchasers of a luxury food like canned pineapple.

There is a useful bibliography, a subject index of uneven value, and an author index.

In conclusion, this book is invaluable to all botanists concerned with pineapples and growers will read it with profit. The general reader will also find most chapters of great interest, although sometimes the unnecessary use of terms like " flower anthesis " and " fruit ontogeny " may act as a deterrent. The illustrations are mostly very good and, with adequate binding, it should be excellent value for £3.

E.F.A.

CABBAGES, BRUSSELS SPROUTS AND OTHER GREEN CROPS. Ministry of Agriculture, Fisheries and Food Bulletin No. 132. (London: H.M. Stationery Office. 1961. Pp. 35, illus. Price 3s.)

Arising from differences in climatic conditions and in market requirements in different parts of the country, there is great diversity in the methods used in the production of cabbages and Brussels sprouts. The Bulletin does not set out to advise on the best methods of growing these crops, since insufficient experimental work has been done for such advice to be soundly based. However, the authors have combined an assessment of the basic needs of the crops with detailed information about established practices in the main growing areas, and have produced a bulletin which should be very useful to all growers of these crops.

Perhaps it is inevitable that, in making generalizations from such a large amount of diverse and detailed information, some points appear to have received too much or too little emphasis, e.g., while it is generally accepted that brassicas need a firm seedbed or plantbed, the soil consolidation procedure recommended and emphasized in this bulletin might result in crop failure on certain types of soil. Experimental work over the past ten years indicates that the general rate of nitrogenous fertilizer suggested here for spring and summer cabbages is too low; many growers already

use much higher rates. The seeding rates, and the ratio of seedbed area to planted area, on the other hand, appear to be unduly generous (possibly by a factor of ten).

The control of pests and diseases is adequately covered, but the statement that heavy liming is a permanent cure for clubroot cannot be accepted, and the use of pure calomel has now superseded 4% calomel in the root dip treatment recommended as a protective measure for plants to be grown in infected soil.

With the current trend towards more prepackaging and quick freezing of vegetables, perhaps the grading and market presentation of cabbages and Brussels sprouts should have been discussed more fully.

Despite the above criticisms, the Bulletin is a valuable publication which should be read by all growers of cabbages and Brussels sprouts.

F.H.

ECONOMIC BOTANY, Vol. 15, No. 1. (The Society of Economic Botany, The New York Botanical Garden, Bronx Park, New York 58. 1961. Illus. Price to non-members $8.00.)

This journal, the official organ of the Society of Economic Botany, is already well known. It contains papers dealing with a diverse range of plants; thus the present Number includes such widely different ones as paulownias, cashew nuts and the bamboo, and discourses on such subjects as New Zealand medicinal plants and the freeze-drying of pollens.

The Society is mainly American but welcomes members from all parts of the world interested in the promotion and stimulation of scientific studies of plants useful to man.

T.N.H.

PLANT GROWTH REGULATION. Edited by R. M. Klein. (Iowa State University Press, Ames, Iowa, U.S.A. 1961. Pp. 850, illus. Price $8.50.)

This handsome volume consists of the proceedings of the Fourth International Conference on Plant Growth Regulation, held at the Boyce Thompson Institute, Yonkers, New York, in August 1959, sponsored by that body and the New York and Brooklyn Botanic Gardens.

Some ninety-seven authors from eighteen countries have contributed sixty-three papers, most of them delivered at the conference, and the discussions they aroused there are included. The latter have seldom added enough to merit the effort they cost the editorial staff, and their recording at the conference itself certainly hampered free exchanges ; this is a practice which symposium organizers should eschew.

The papers have been rather unsatisfactorily grouped under five very artificial main headings: (i) naturally occurring plant growth substances—seven articles covering natural auxins and certain aspects of their metabolism, and natural inhibitors; (ii) mechanisms of auxin activation and inactivation—six rather mixed papers; (iii) synthetic growth regulants—eighteen articles, somewhat dominated by phenoxy compounds and auxin, but including some on new materials or approaches; (iv) gibberellins—a disproportionate section of eighteen articles covering most aspects of work on these fashionable substances; (v) other growth regulators and some general papers, fourteen in all.

The title—*Plant Growth Regulation*—suggests a balanced treatment of this enormous field, which is certainly lacking in this volume and, in the reviewer's opinion, it is regrettable that in so much of the work represented the *plant* has often been lost sight of altogether in the rush to capture a new chemical or devise an often airy theory of action for an old one.

No clear pattern emerges from the welter of information presented, and consequently the book as a whole is not as exciting as it should have been, though there are many particular papers which will appeal to the specialist within the general field.

The format is pleasant, the paper excellent, the line illustrations profuse and clear (the few photographic ones are not so good, but not vitally important), the bibliographies of most papers extensive, and the subject index to the whole volume very good—in fact, a great deal of editorial care has been bestowed on the book.

H.W.B.B.

PUBLICATIONS RECEIVED

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4. Where a paper is of a highly technical nature it should be preceded by a brief **synopsis**, in which its contents are simply and clearly stated for the benefit of non-technical readers.

5. **References to literature** may be by numbers (in brackets) in the text corresponding to a numbered list at the end of the paper or by the Harvard system (author's name and date of publication). By either method, the papers cited should be listed alphabetically according to authors' names, followed by the date of publication. The title of the paper should next be given in full, followed by contracted, but strictly intelligible, title of source of publication, the volume and page numbers. Authors are responsible for the accuracy of their lists of references and should check them carefully in both typescript and proof.

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10. The suggested **abbreviation** for the title of this publication is *J. hort. Sci.*

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